Energy, Air Quality, Water and Greenhouse Gas Co-Benefits of Renewable Power Generation and Fuels: Roadmap Workshop

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Draft Roadmap Workshop
Sacramento, CA
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Combustion
Fuel Cells
Distributed Power

ADVANCED POWER & ENERGY PROGRAM
UNIVERSITY of CALIFORNIA · IRVINE

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"Research Powers the Future"

Outline

- **Project Overview**
- Technology and Fuels Identification and Assessment
  - Technology R&D Needs
  - Impacts (GHG, AQ, Water) R&D Needs
  - Biopower R&D Needs
- Co-Benefits Assessment Methodologies
- Discussion

Problem Statement

Various drivers in CA for shifts to renewable technologies and fuels

- **Renewable Electricity Standard (RES) → 33% by 2020**
- **Variability of cost and supply from traditional fuels**
- **Focus on energy conservation**
- **Reduce greenhouse gas (GHG) emissions and improve air quality (AQ)**

- **Renewable pathways may have positive or negative impacts**
  - **Emissions and water resource impacts not as well characterized and understood as for traditional power generation**

- **Need for additional research to identify co-benefits/dis-benefits of technologies and pathways in order to inform decision makers**
  - **Necessitates the development of a roadmap to:**
    - Identify knowledge gaps and research needs to guide the Electric Program Investment Charge (EPIC) and Natural Gas RD&D programs of the Energy Commission to assist California in securing renewable power generation in environmentally sound ways, e.g., maximizing co-benefits

Goals and Objectives

Project Goal

- **Develop a road map identifying state of knowledge, research gaps and recommended research pathways with regards to:**
  - **Identifying and assessing AQ, GHG, and water resource benefits and dis-benefits from renewable technologies, fuels, and pathways**

Project Objectives

1. **Conduct research and host public workshops and surveys to:**
   - **Identify gaps and research needs that address environmental impacts of alternative energy and fuel technologies**
   - **Identify gaps and research needs for methods to analyze energy, environmental and climate change co-benefits**
2. **Develop a roadmap**
   - **Identify state of knowledge, research gaps, and recommended research pathways to evaluate potential air quality impacts and energy, climate change and water co-benefits of traditional, alternative and renewable power and fuels in California**

Approach

- Task 1 – Project Management
  - Reporting, match funds, permitting, etc.
- Task 2.1 – Alternative Energy and Fuel Technology Identification and Analyses
  - Identify, review and assess relevant alternative energy technologies and fuels
  - Develop a technology assessment to determine the scope of the roadmap in terms of technologies and pathways and provide relevant insights

Previously Completed

- Task 2.2 – Energy, Air Quality, Water and Climate Change Co-benefits Analyses
  - Identify and assess current methods used to determine co-benefits
  - Develop a co-benefits methodology assessment to address shortcomings and knowledge gaps and provide relevant insights
- **Task 2.3 – Roadmap Development**
  - **Identify the state of knowledge and research gaps relating to the benefits and dis-benefits of renewable power generation and fuels**
    - Integrate findings of previous tasks → Task 2.1 and 2.2
  - **Recommend research pathways to maximize, recognize and quantify the energy and environmental co-benefits of using renewable resources in CA**

Approach

- **Public workshop hosted September 2012 to facilitate critique of initial results and attain feedback from a variety of stakeholders**
  - **Feedback analyzed and incorporated into Technology Assessment and Co-benefit Assessment Methodologies Reports**
  - **Reports comprised the basis for initial Roadmap Draft**

- **Web-based survey developed and disseminated through various channels to participants**
  - **Final assessment conducted on input from 105 respondents**
  - **Any important and relevant insights gained included in draft roadmap**

Summary of R & D Needs

Categories of Research Goals

1. Furthering the state of knowledge in selected research areas to assist in developing strategies to maximize co-benefits from the deployment of renewable power

2. Address technological barriers and research gaps to the adoption of selected technologies in environmentally sound manners

3. Improve methodologies to characterize, assess, and quantify AQ, GHG, and water co- and dis-benefits from renewable power

Priority R & D Need	Research Goal			GHG Impacts	AQ Impacts	Water Impacts	Term (S M L)
	1	2	3				
Technologies and Fuels							
Accurate assessment of the environmental impacts of natural gas generation (e.g., carbon footprint of non-traditional gas reserves, emissions of non-traditional gas use)	X			++	+	+	S
Detailed evaluation of complimentary and/or back-up generation required for various renewable penetrations	X			+	++	+	S-M

Summary of R & D Needs

Environmental Impacts

- **Potential importance to stated environmental impact category**
  - + = positive

Priority R & D Need	Research Goal 1	Research Goal 2	Research Goal 3	GHG Impacts	AQ Impacts	Water Impacts	Term (S M L)
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Summary of R & D Needs

Temporal Project Scope

- **Variation in potential research task horizons**
  - S = short-term
  - M = medium-term
  - L = long-term

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Introduction

<u>Technology and Fuel Identification and Analyses</u>

- **Focus on power generation sector**
  - **Some resources could be used for different sectors, e.g., transportation**
- **Potential California and regional technologies for 2020-2050**
  - **Review relevant literature/status reports/technology assessments of renewable power generation technologies, fuels, and pathways**
  - **Develop technology assessment of renewable power and fuels pathways with the potential for significant deployment in roadmap horizon**
    - Identify and discuss potential for environmental co- and/or dis-benefits
    - Relevant insights, research findings, and background information
    - Identify associated knowledge gaps and research needs for optimized environmental deployment of technologies in California

Technology Identification

Pathway, Technology, and Fuel Identification

- **Renewable pathways with potential impacts in roadmap horizon (2020-2050)**
  - **Current eligibility for CA Renewable Portfolio Standard**

- **Solar**
  - Photovoltaic (PV)
  - Concentrated Solar Thermal (CST)
- **Wind**
- **Geothermal**
- **Biopower**
  - Biomass
  - Municipal Solid Waste (MSW)
  - Biogas
    - Digester Gas (DG)
    - Landfill Gas (LFG)
    - Pipeline Injection
  - Biodiesel
  - Algae-based fuels
- **Small Hydroelectric**
  - Conduit
  - < 30 MW
- **Fuel Cells (FC)**
  - Biogas
  - H_2 from renewable pathways
- **Ocean Energy Devices**
  - Wave
  - Tidal
  - Thermal
- **Complementary Technologies**
  - E.g., storage

Technology Identification

Initial Workshop Feedback

- **Additional technologies/fuel pathways**
  - **Dedicated energy crops**
    - Algae-based fuels→ high potential for co-benefits
  - **Renewable hydrogen (stationary power applications)**
    - Electrolysis of water, biofuel/biogas production
  - **Pipeline injection of bio-methane**
    - Further research needed
      - Identifying/tracking injected resources
      - Health concerns → e.g., vinyl chloride
- **Additional associated/complimentary technologies**
  - **Energy storage technologies**
    - Importance in deployment of RERs at high levels
  - **Carbon capture and storage (CCS)**
    - Co-deployment with biopower technologies
- **Importance of pathway sub-division**
  - **Wind- offshore vs. onshore, Solar- PV vs. CST**
  - **Geothermal- thermal, EGS, heat pumps, etc.**

Technology Assessment

Technologies differ by state of commercial deployment readiness

– **Advanced pathways have potential for high benefits but require further development**

Current
- Solar PV
- Wind
- Geothermal
- Biopower
  - Combustion

+

Short/Mid
- Advanced PV
- Utility-scale CST
- Advanced Biopower
  - Biogas – fuel cell
- Advanced energy storage

+

Mid/Long
- Advanced Biopower
  - Gasification
- Ocean Energy
- Algae-based Fuels

2013 — **2020** — **2050**

- **Currently available technologies**
  - **Optimized systems level integration with California grid**
    - Reduce back-up generation, curtailment
    - Improve grid stability and reliability
    - Upgrade (Smart) grid technologies to enhance manageability
  - **Improve technology performance**
    - Efficiencies and power output → reduce costs, land-use
    - Reduce/prevent emissions from biopower technologies
  - **Reduce transmission constraints**
    - Stream-line permitting for new projects

Technology Assessment

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Mid/Long
- Advanced Biopower
  - Gasification
- Ocean Energy
- Algae-based Fuels

2013 → 2020 → 2050

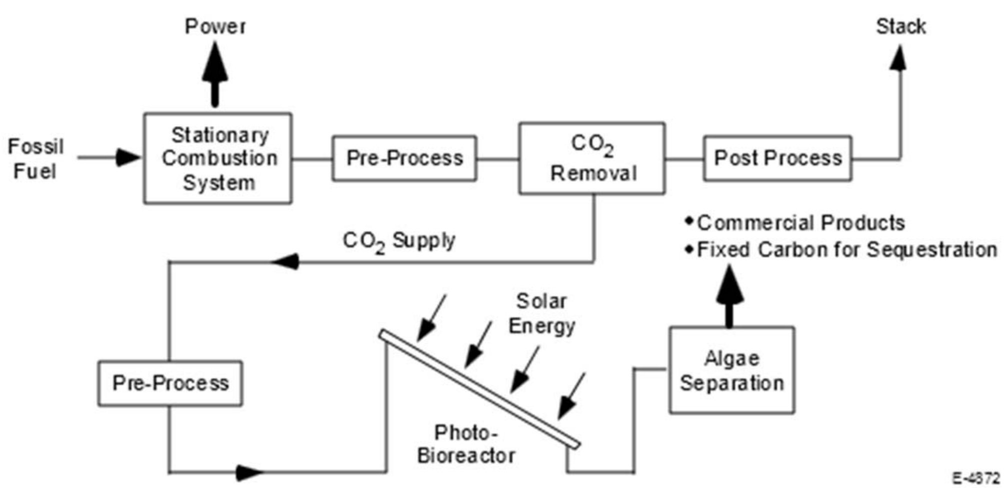
- **Advanced renewable technologies require additional considerations**
  - **Assessment of California resource potential**
    - Evaluate expected/prospective power contributions
  - **Advance technology development**
    - Many require performance enhancements to achieve feasibility
  - **Identify and characterize associated impacts**
    - Environmental
    - Energy
    - Economics

Technology Assessment: Algae Fuels

Liquid or gaseous fuels produced from micro- or macro-algae have the potential for very high co-benefits

- Utilized in heat engines/fuel cells to produce power and co-products
- Can be integrated in carbon capture system for point source emissions

Microalgae-based carbon capture system



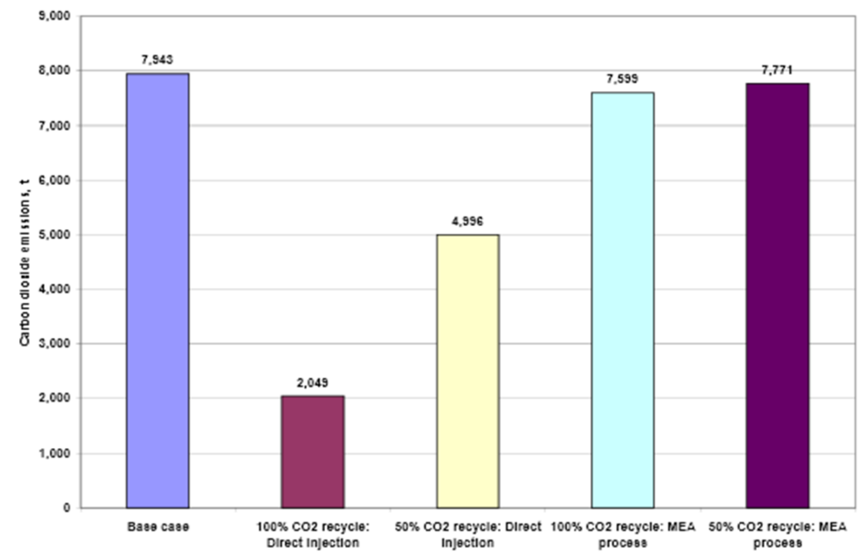


Figure 9. Fossil CO_2 emissions for coal firing versus coal/algae cofiring.

Source: http://www.netl.doe.gov/publications/proceedings/04/carbon-seq/123.pdf

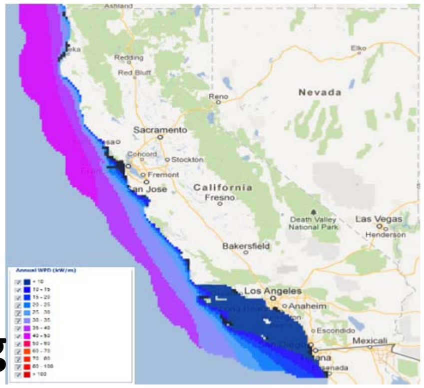
R & D: Algae Fuels

Summary: Major technological and economic barriers currently prevent production at-scale with economic feasibility

- Research into basic and applied algae fuel for applications
- Demonstration projects of sustainable micro-algal systems, e.g., carbon capture and storage (CCS) from power plants
- Further understanding of life cycle impacts to elucidate co- and dis-benefits

Priority Algae Fuel R & D Need	Research Goal 1	Research Goal 2	Research Goal 3	GHG Impacts	AQ Impacts	Water Impacts	Term (S M L)
Thorough assessment of potential CA algae fuel production	X			++	++	++	S
Demonstration of scalable, commercially viable production facilities in CA		X		+++	++	++	M-L
Designing/evaluating integrated cultivation and digestion systems • *Optimization of cultivation in waste water* • *Enhancement of digestibility and conversion rates*		X		++	++	+++	M-L
Elucidation of environmental impacts to assess co-benefits • *Life cycle GHG emissions for specific systems and pathways* • *Emission impacts for displacement and direct impacts for CCS* • *Water resource impacts for usage and quality*	X			++	++	++	S-M

Technology Assessment: Ocean Energy



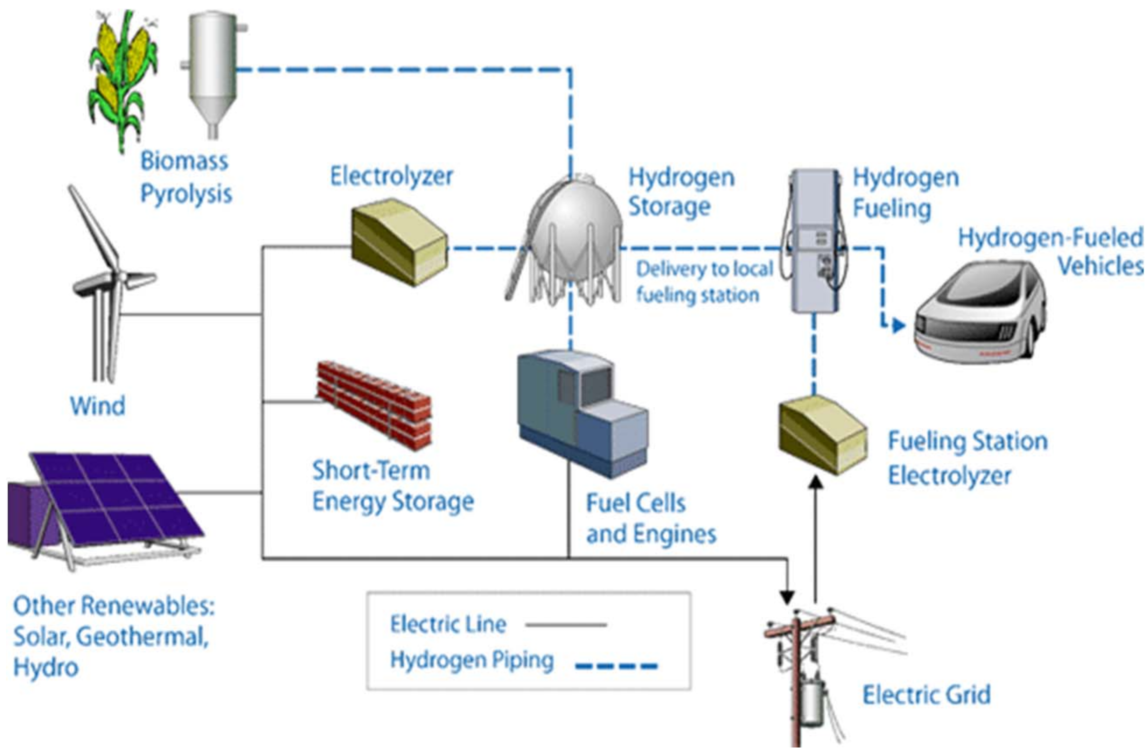
- **Large resource base for California**
  - **110 TWh/yr recoverable wave energy resource[1]**
  - **204 MW potential from tidal streams[2]**
- **Require further development**
  - **Optimal array design, development, modeling, and testing**
    - Efficiency improvements, maximization of power → Reduce costs, impacts
  - **Need for full-scale CA demonstration and deployment projects**
- **Environmental concerns require insight**
  - **Aesthetics**
    - Noise, visual
  - **Resource Hydraulics**
    - Local current patterns, sediment dynamics
  - **Toxicity of biofouling prevention materials**
    - Paints, chemicals , hydraulic fluids
  - **Ecological impacts**
    - Impacts on migratory and resident organisms, habitats and plant life

Source(s): [1] EPRI 2011 Mapping and Assessment of the United States Ocean Wave Energy Resource
[2] Georgia Tech Research Corporation 2011 Assessment of Energy Production Potential from Tidal Streams in the U.S.

Technology Assessment: Fuel Cells

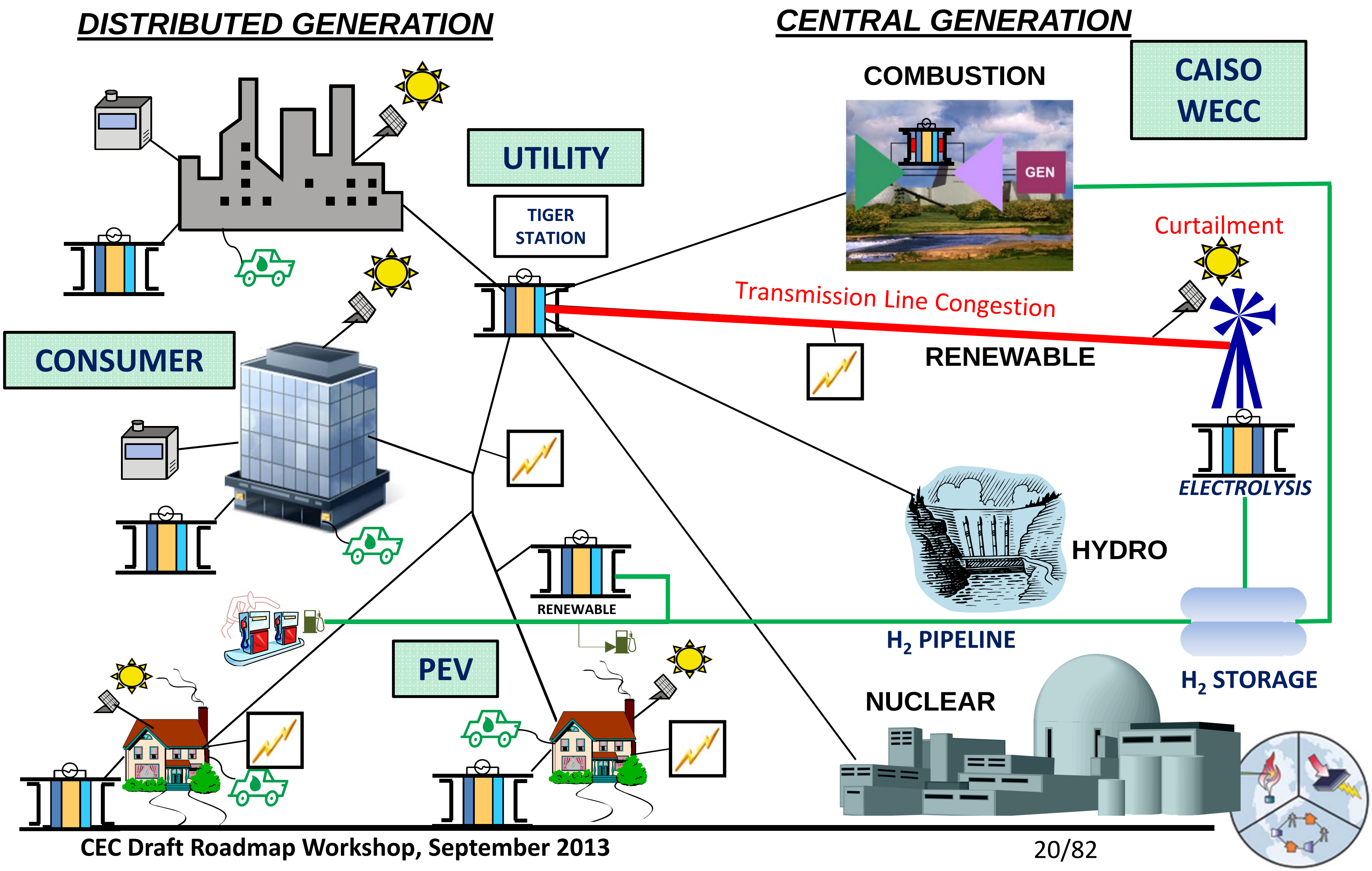
Fuel cells have a range of potential applications to support and/or enhance renewable deployment including co-benefits

- Grid applications e.g., tiger stations
- Integrated wind/solar hydrogen storage systems
- Biopower applications



Source: http://www.nrel.gov/hydrogen/proj_wind_hydrogen.html

Technology Assessment: Fuel Cells



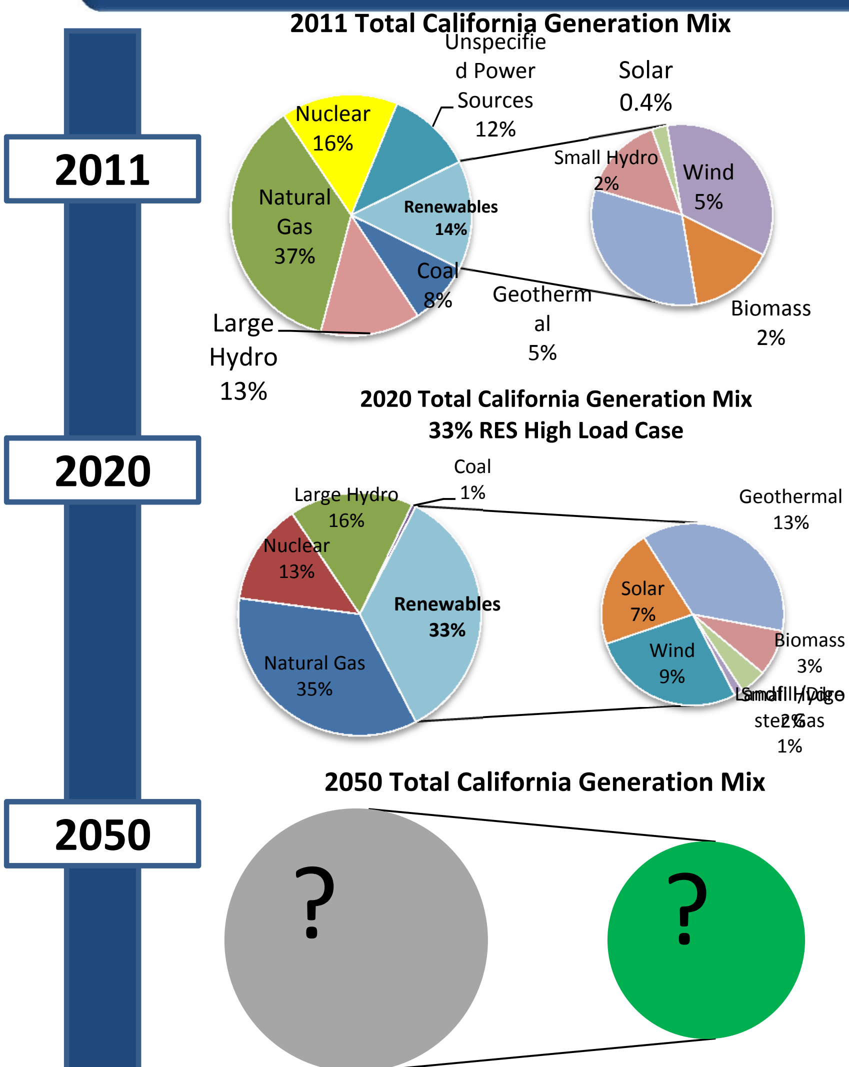
R & D: Technologies and Fuels

Summary: Advanced pathways (mid-long term) could yield substantial co-benefits but require technology advancement

- Further understanding of opportunities for deployment
- Demonstration projects at-scale needed in CA

Priority R & D Need	Research Goal			GHG Impacts	AQ Impacts	Water Impacts	Term (S M L)
	1	2	3				
Advancement of ocean energy technologies, including CA resource assessments and full-scale demonstration projects	X	X		++	++	++	M
Advancement of algae-based fuels for power generation, including technological, economic, and resource assessment	X	X		+++	++	+++	M-L
Advancing the technical performance of fuel cells and BOP technologies to reduce cost		X		++	+++	+++	S-M
Integrated use of fuel cell systems, e.g., TIGER station, renewable fuel, dynamic dispatch to complement wind/solar		X		++	+++	+++	S-M
RER-fuel cell integrated systems for energy storage, e.g., improve efficiencies, hydrogen yields, reliability ,reduce costs • *Utility-scale demonstration projects needed in CA*		X		+++	+++	+++	M-L

Technology Assessment



Short term drivers

- **Established policy**
  - Renewable Electricity Standard
  - AB 32
  - California Solar Initiative
- **Current technological maturity**
  - Cost, performance

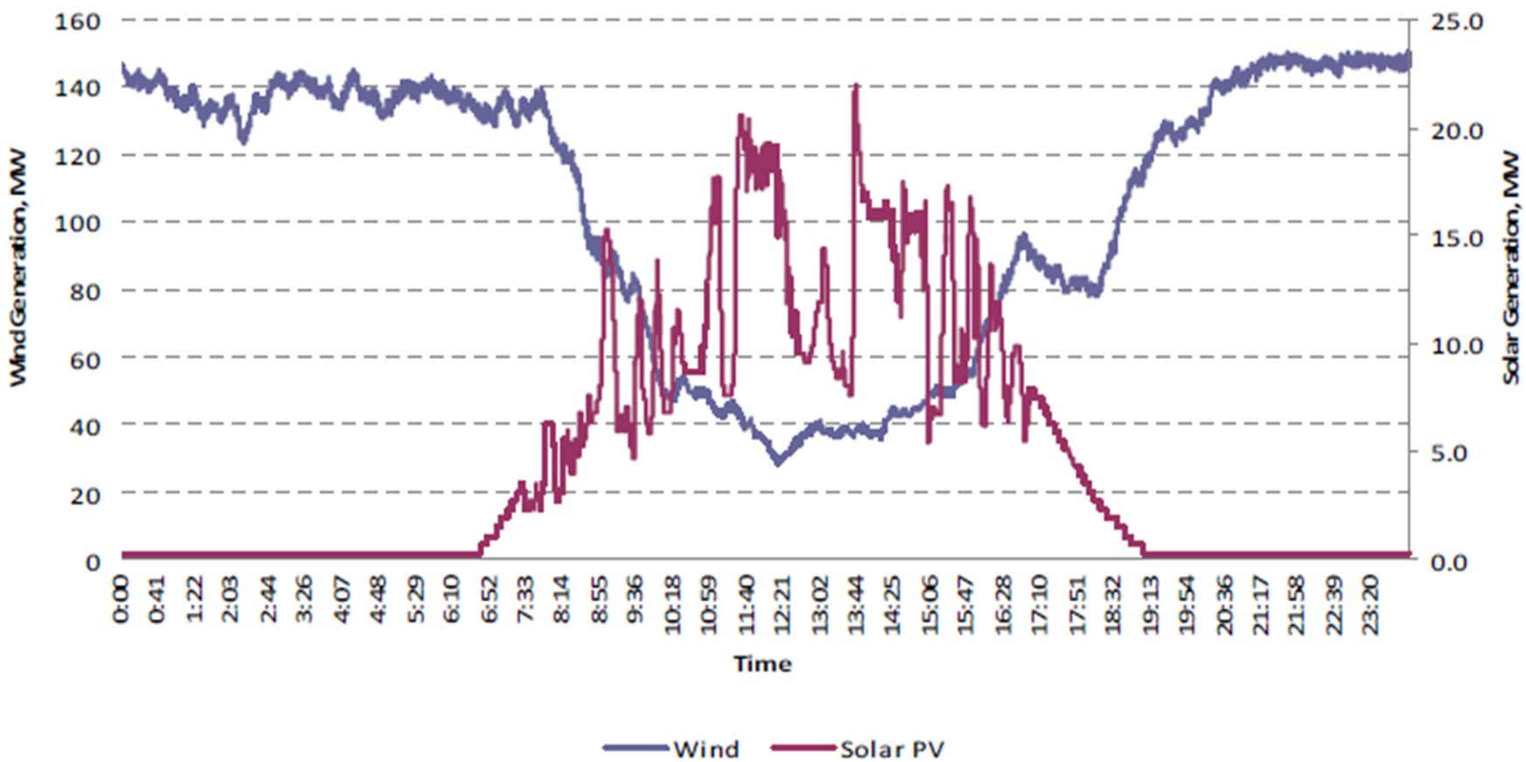
Long term drivers

- **Future policy and programs**
- **Rate of technological progress**
- **Resource availability**
- **Future load demands**
- **Socio-political factors**

Source: CEC 2012 http://energyalmanac.ca.gov/electricity/total_system_power.html
Source: CARB 2012 Proposed Regulation for a California Renewable Electricity Standard

Technology Assessment: Complimentary

Complementary technologies necessary to balance intermittencies associated with some renewable power generation pathways



- ude

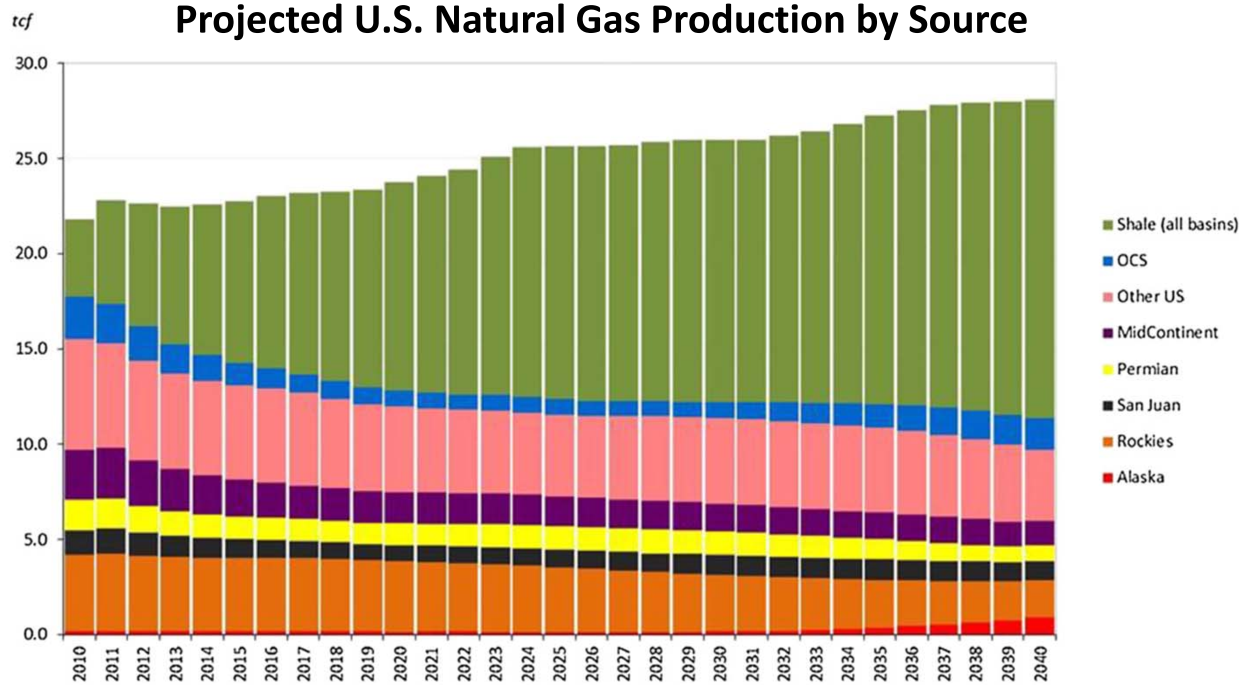
Source: Integration of Renewable Resources Operational Requirements and Generation Fleet Capability at 20% RPS (CAISO, 2010)

Technology Assessment: Natural Gas

Impacts of renewables largely relative to gas-fired generation in CA

- **Domestic supply largely shifting to non-traditional reserves (Shale)**
- **California imports majority (88%) of utilized gas reserves**
  - Significant amounts from areas supporting shale gas recovery

Projected U.S. Natural Gas Production by Source



Source: U.S. EIA 2011a

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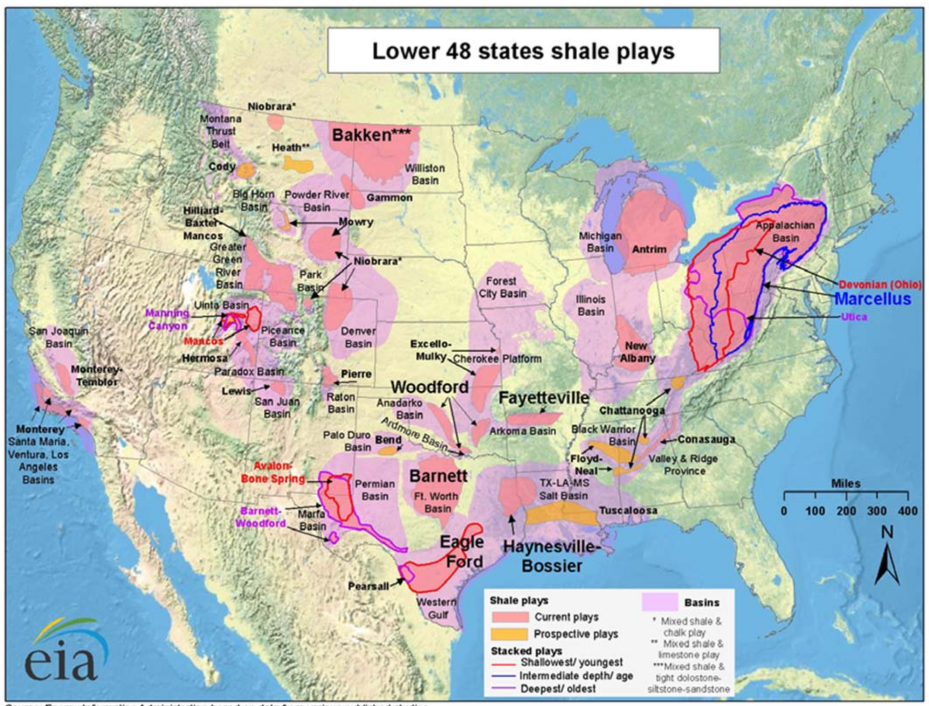
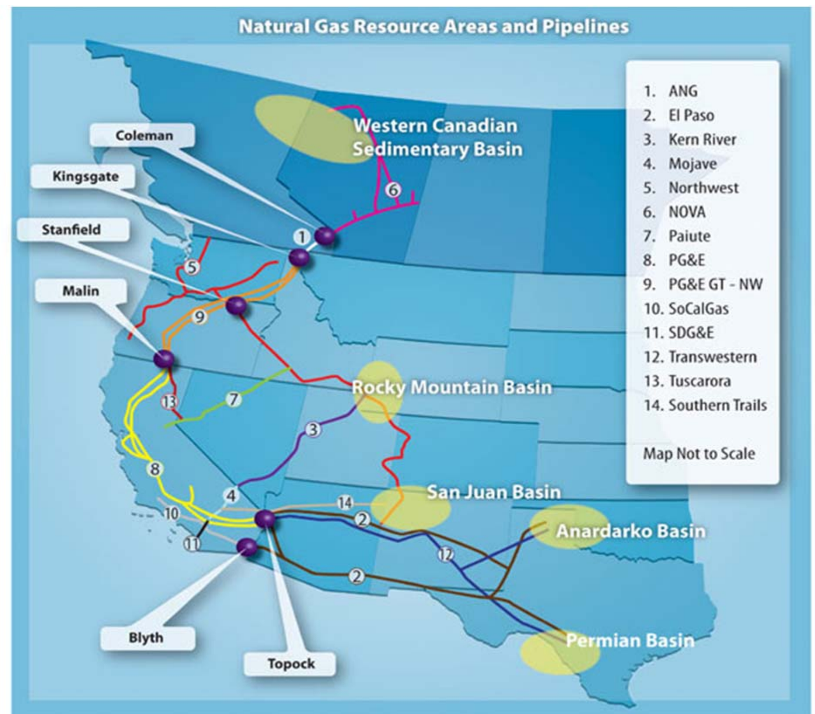


Source: Energy Information Administration based on data from various published studies.
Updated: May 9, 2011

Source: U.S. EIA 2011a



Source: CEC California Energy Almanac

Technology Assessment: Natural Gas

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- **Domestic supply largely shifting to non-traditional reserves (Shale)**
- **California imports majority (88%) of utilized gas reserves**
  - Significant amounts from areas supporting shale gas recovery

- **Environmental concerns associated with recovery processes**
  - **GHG emissions →potentially higher than traditional gas**
  - **Surface water consumption and contamination**

- **Important to include accurate LCA of gas in CA assessments**
  - **Accurate characterization of imports**
  - **Detailed understanding of emissions impacts at each life cycle stage**
    - Exploration, recovery, processing, transport
  - **Understanding of use for power generation vs. other, e.g., residential**
  - **Could undervalue impacts of renewable resource deployment**

Technology Assessment

Initial Workshop feedback

- **Importance of including impacts of co-deployed technologies**
  - **Any required transmission technologies/infrastructure projects**
  - **Grid balancing/reliability technologies**

- **CA demand load profile identified as potential knowledge gap that is being addressed by several groups (e.g., LBNL, CAISO)**
  - **Coordinated analyses via collaboration would be beneficial**

- **CAISO studies could provide updated information on complementary generation requirements for meeting CA regulatory mandates**
  - **Development of standardized comparison cases for future assessments**
    - E.g., (1) Baseload, (2) State-of-the-art NGCC, (3) State Average

R & D: Baseline Generation

Summary: Impacts of renewables relative to displaced "baseline"

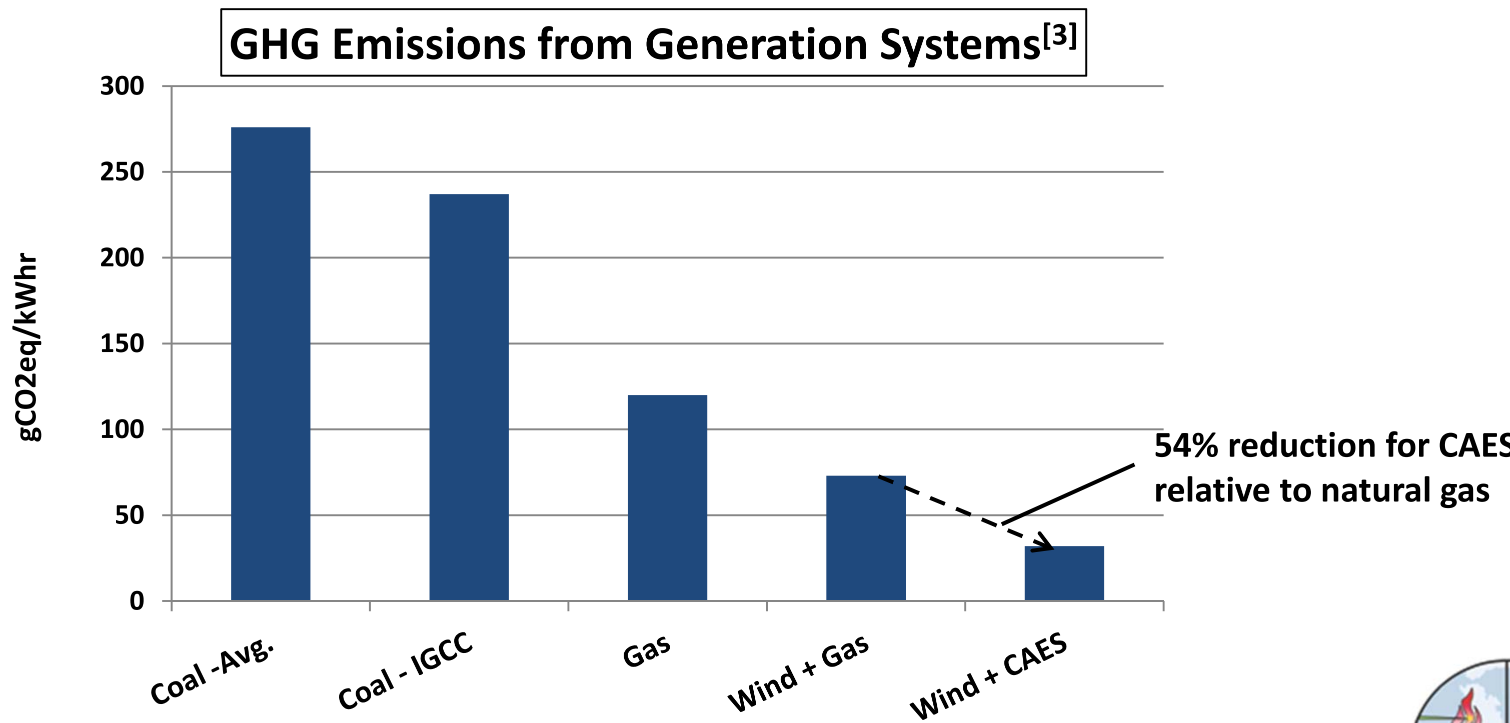
- **Requires accurate, thorough understanding of impacts of natural gas**
- **Evolution of California's power system will influence co- and dis-benefits**
- **Detailed grid modeling to account for impacts of variable resource integration**
  - Evaluate complex systems level dynamics
  - Assess co-deployed complementary or back-up technologies

Priority R & D Need	Research Goal			GHG Impacts	AQ Impacts	Water Impacts	Term (S M L)
	1	2	3				
Detailed grid modeling projecting the evolution of the California power system (e.g., load demands, dynamics)	X		X	+	+	+	S
Detailed evaluation of complimentary and/or back-up generation required for various renewable penetrations	X			+	++	+	S-M
Accurate assessment of the environmental impacts of natural gas production, T&D, and use (e.g., carbon footprint of non-traditional gas reserves, emissions of non-traditional gas use)	X			++	+	+	S
Support the co-deployment of additional low impact complementary strategies, e.g., smart grid, control	X	X		+++	+++	++	M-L

Technology Assessment: Energy Storage

Advanced energy storage needed to enhance deployment levels and improve system operation while minimizing emissions

- Necessary to achieve maximum environmental, economic, and technical benefits
- Deep CA GHG reductions (90-100%) requires AES with capacities minimum 65% of peak load, and large enough to permit seasonal energy storage[2]



[1]CESA 2010, [2] Hart & Jacobson 2012, [3] Greenblatt et al., 2007

Technology Assessment: Energy Storage

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Avoided Costs from Fossil Peaker Plant Substitution[1]	
Societal Level	Grid System Level
– Reduce GHG emissions	– Energy time-shifting capabilities
– Improve AQ	– Voltage support
– Reduced water resource impacts	– Electric supply reserve capacity
– Increased renewable integration	– Transmission congestion relief
– Support Smart Grid implementation	– Frequency regulation
– Streamlined permitting	

[1]CESA 2010, [2] Hart & Jacobson 2012, [3] Greenblatt et al., 2007

R & D: Energy Storage

Summary: Key barriers to Energy Storage deployment in CA[1]

- **Regulations/utility processes that disfavor energy storage**
  - No formal mechanism for recovering/recognizing full value of AES
- **Costs**
  - Commercialization stage, material expense, lack of manufacturing at scale
- **Lack of awareness/valuation of energy storage benefits**
  - Decision makers unaware of availability, effectiveness, & benefits

Priority R & D Need	Research Goal			GHG Impacts	AQ Impacts	Water Impacts	Term (S M L)
	1	2	3				
Advancement of energy storage in utility applications to support renewable deployment and integration • *Demonstration projects of integrated commercial/distributed scale applications*	X	X		++	++	+	S-L
Support progress of technologies with the potential for significant capacity additions in CA, e.g., reduced costs		X		++	++	+	S-M
Identification and analysis of opportunities for CA deployment	X			++	++	+	S

[1] Elkind 2010

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Technology Assessment: Environmental Impacts

Renewable Technologies/Pathways

Thermo-cycle can require water (e.g., cooling, working fluid)

- Water consumption
- Water quality
- Air quality

Biopower

Geothermal

Fuel Cells

- Renewable Fuel

Hydroelectric

Solar Power

- Photovoltaic (PV)
- Concentrated Solar (CSP)

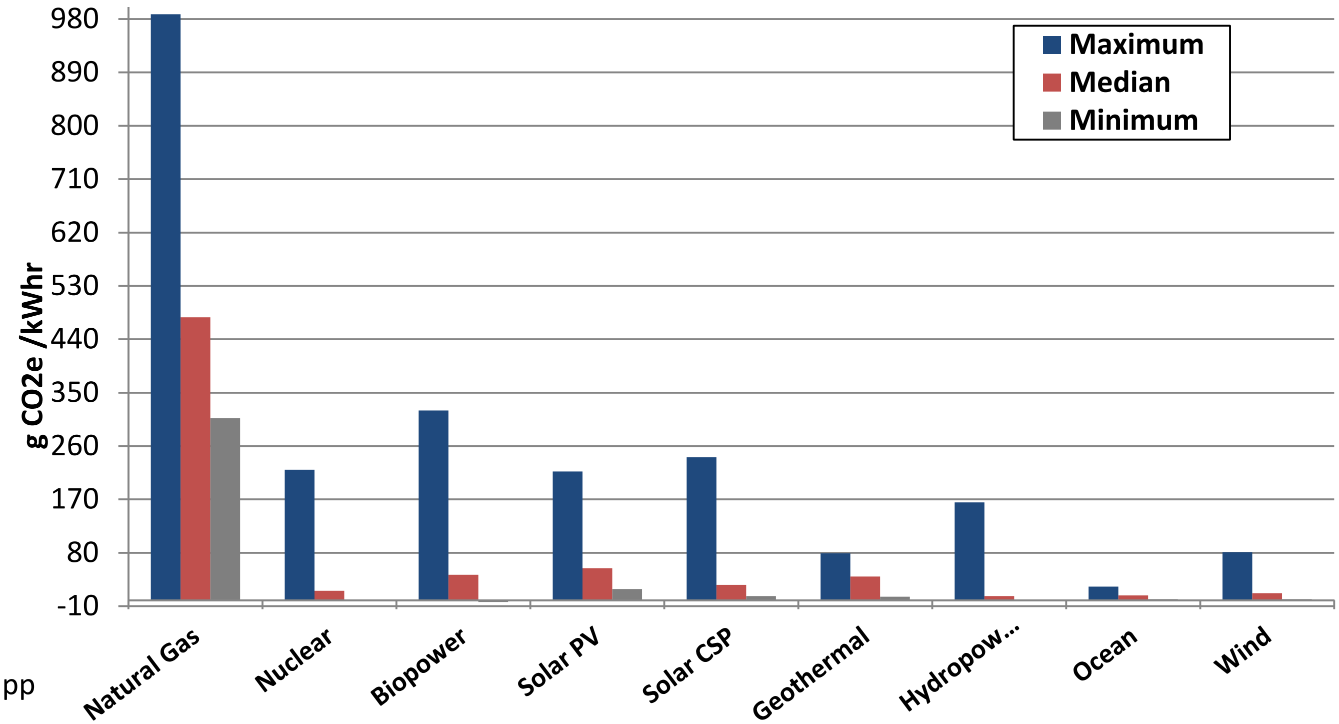
Wind Power

Ocean Energy

Technology Assessment: GHG

Impacts determined by net emissions over technology lifetime relative to net emissions of displaced generation

- **Requires comprehensive life cycle assessment (LCA)**
  - Accurately account for net impacts of deployed vs. displaced
  - Avoid problem shifting →LCA stage, region, environmental impact

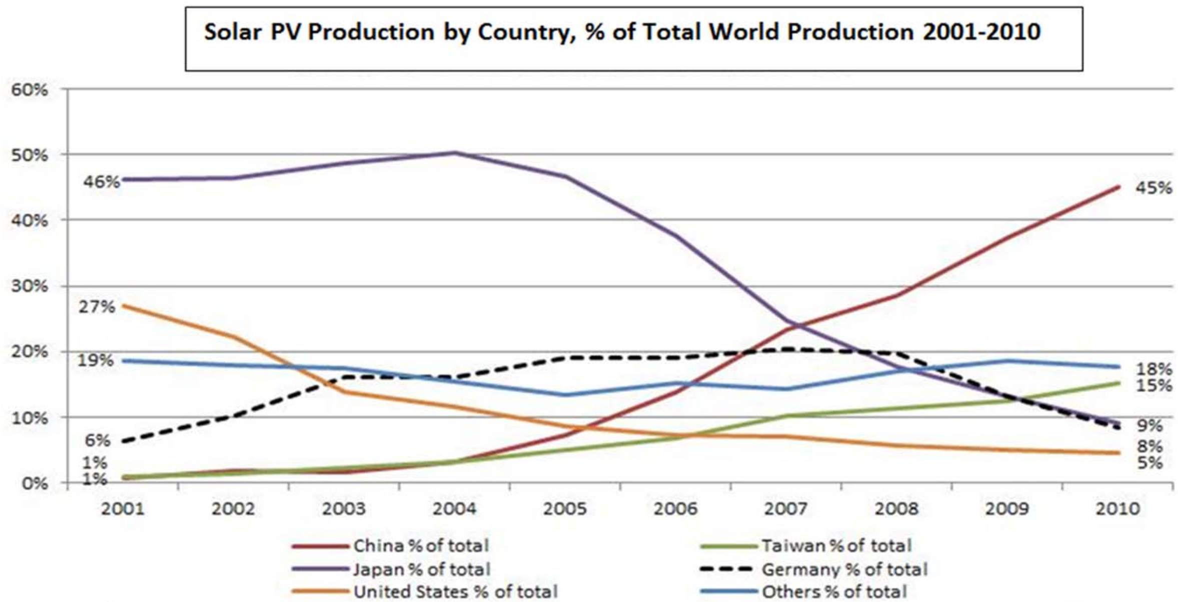


Source: NREL 2012 http://en.openei.org/apps/LCA/

Technology Assessment: GHG

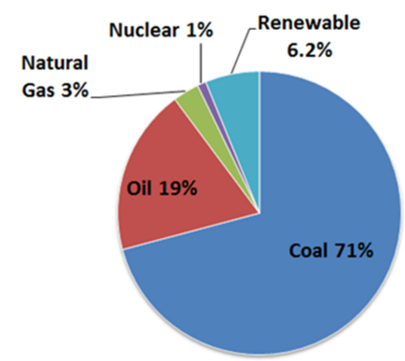
Disparity in available LCA results complicates California estimates

- **Data uncertainties & availability, rapid rate of technological modification**
- **Weighting/valuation of disparate effects**
- **Differences in assumptions, methodologies, boundaries, databases, regions**
  - Plant → capacity, lifetime, location, output
  - Up/Downstream→ materials, manufacturing, transportation
    - **Underlying energy infrastructure**



Source: EPI 2010

Primary Energy Consumption by Fuel



China

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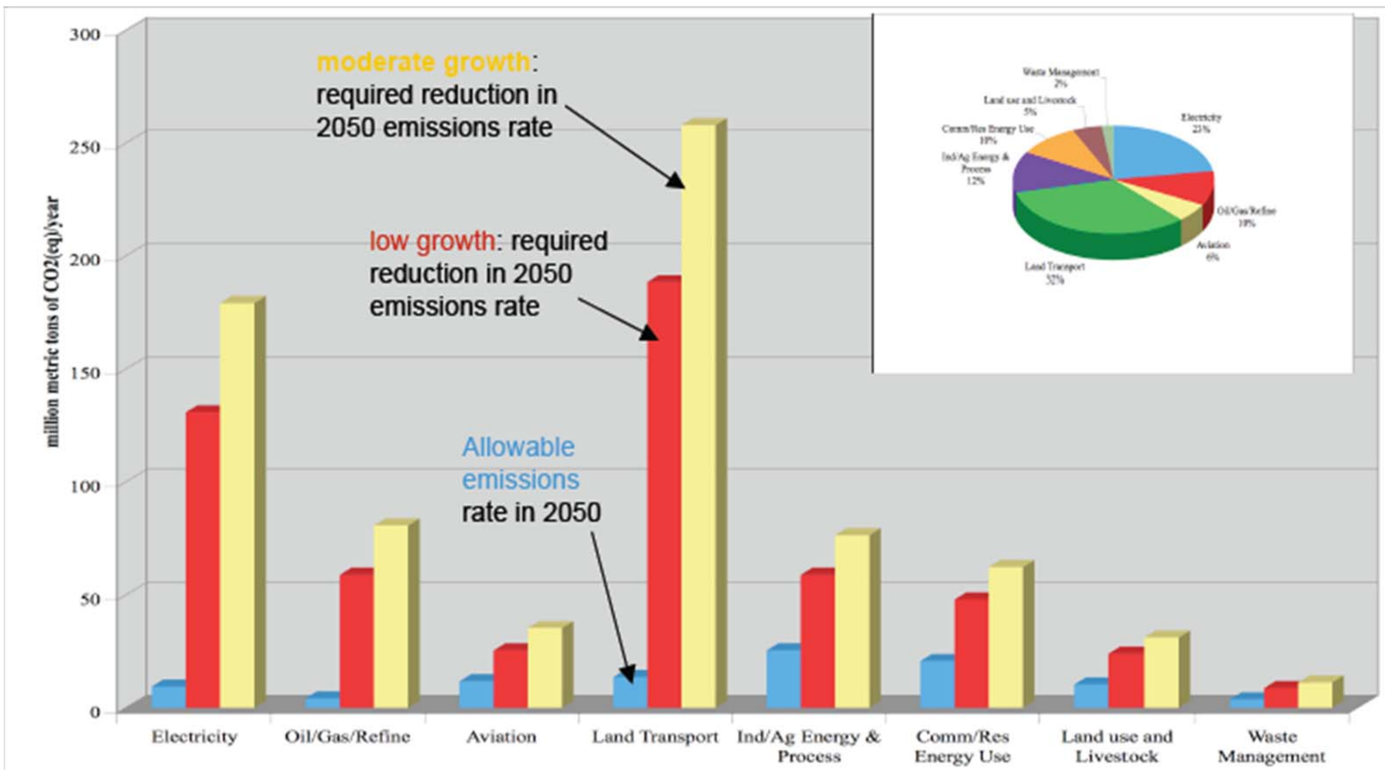
Knowledge Gaps

- **LCA of California-specific renewable resource deployment**
  - **Technology Level**
    - Production and transportation, operation and performance parameters
  - **Regional characteristics**
    - Insolation, wind dynamics, transmission considerations
  - **Integration into future California power generation system**
    - Systems level dynamics, complimentary generation
    - Out-of-state vs. in-state displacement

Technology Assessment: GHG

Differences across/between renewable technologies

- **Importance increases with integration level**
- **Long-term (2050) California GHG goals require dramatic emission reductions from power generation (90-95%)**



Source: Steven Schiller 2007 Implications of Defining and Achieving California's 80% Greenhouse Gas Reduction Goal

R & D: GHG Impacts

<u>Summary</u>: Global nature of climate change necessitates detailed LCA emissions accounting for renewable and displaced pathways in CA

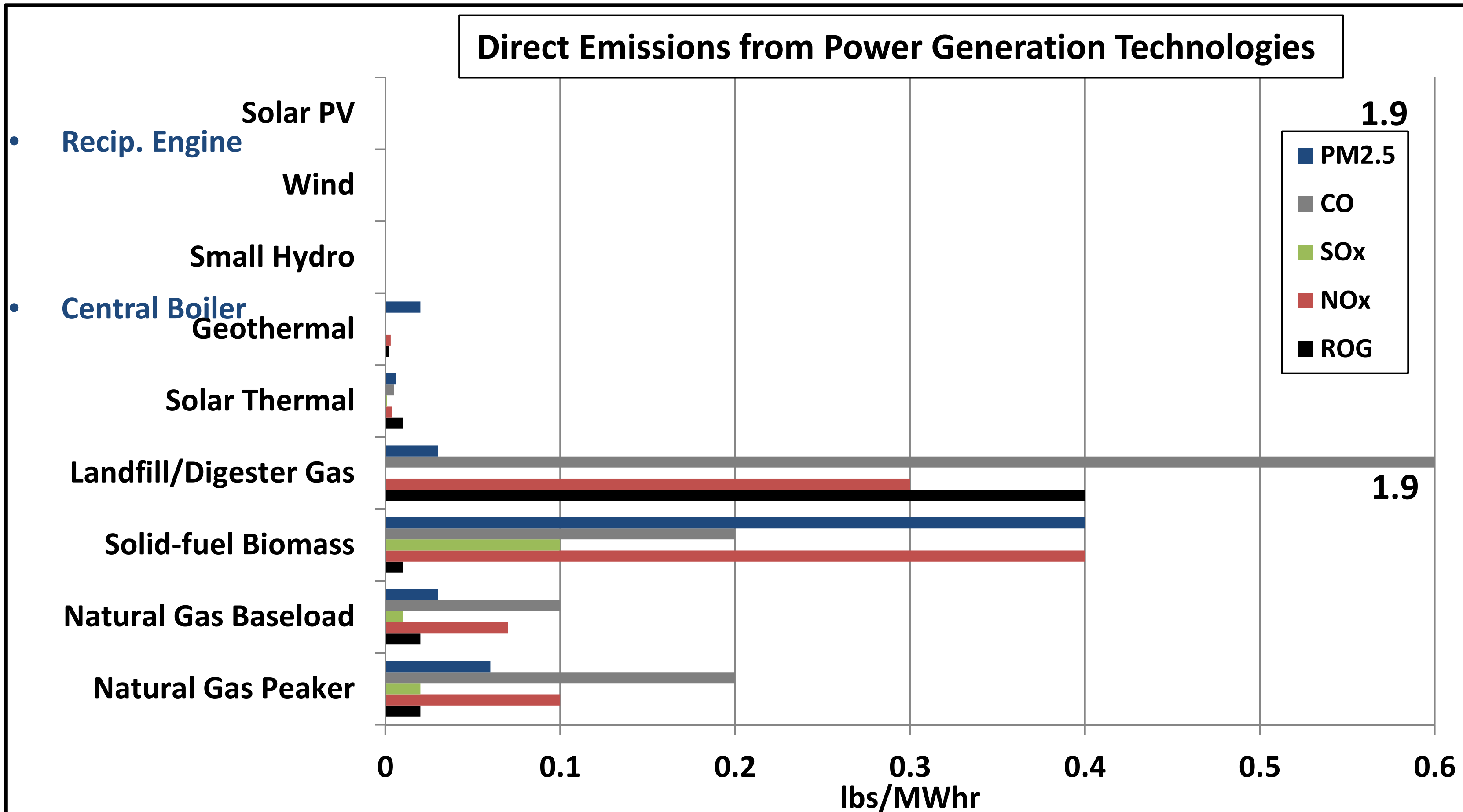
- **Accurate assessment requires “cradle-to-grave” perspective**
- **Differences between renewable resources will increase in importance**

Priority R & D Need	Research Goal			GHG Impacts	AQ Impacts	Water Impacts	Term (S M L)
	1	2	3				
Updated LCA for renewable pathways with specific technology and CA boundaries and inputs	X		X	+++	+	+	S
Accurate assessment of GHG impacts of natural gas recovery, storage and transmission (esp. non-traditional)	X			++	+	+	S
GHG emission impacts of the dynamics of grid operations with high renewable use and complementary technologies	X		X	+++	++	+	S

Technology Assessment: AQ

Direct emissions from biopower systems can be greater than gas

– **Represent current commonly used conversion devices**



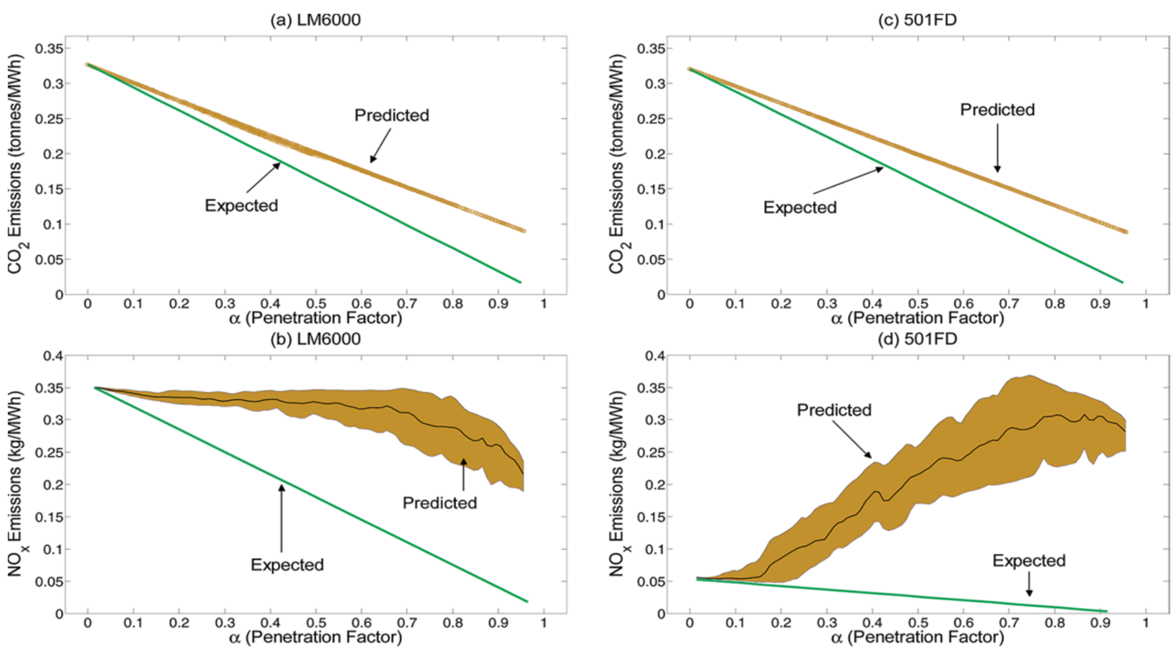
Source: CARB 2010 *Proposed Regulation for a California Renewable Electricity*

Technology Assessment: AQ

Emissions from complementary technologies must be considered

- **Use of traditional (fossil) technologies can reduce benefits**
  - Dynamic generator operation can increase relative emission rates

Expected and Predicted Emission Rates for a Wind/Solar and Gas Turbine System



Source: Katzenstein and Apt 2009

Technology Assessment: AQ

Emissions from complementary technologies must be considered

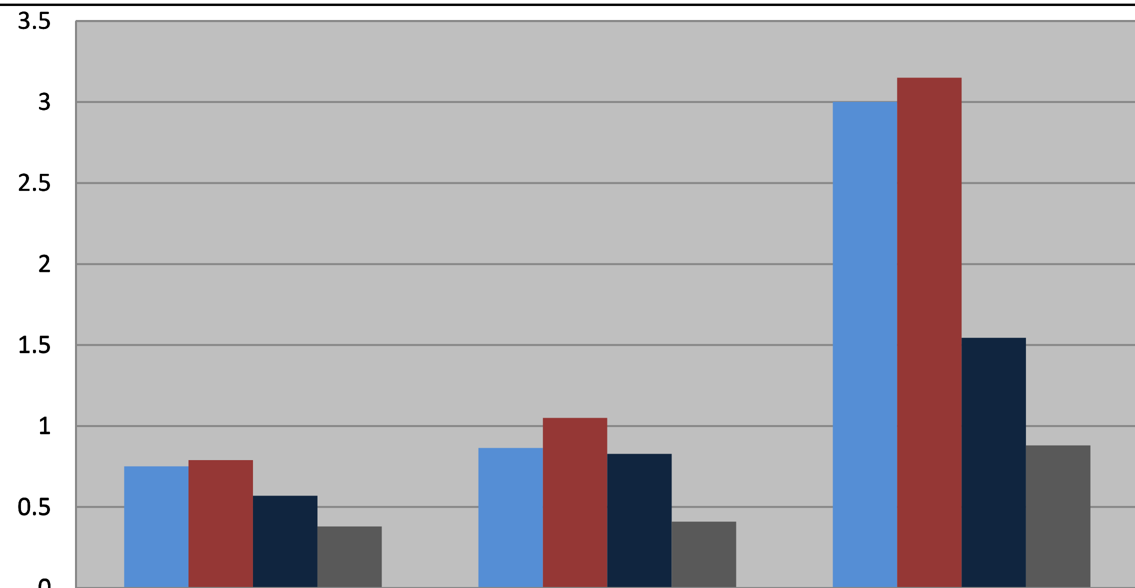
- **Use of traditional (fossil) technologies can reduce benefits**
  - Dynamic generator operation can increase relative emission rates

- **Further understanding and development of strategies to mitigate impacts of altered grid dynamics from intermittencies**
  - **Co-deployment of low impact complementary technologies can mitigate impacts and maximize co-benefits**
  - **Avoid unforeseen dis-benefits, e.g., localized emission increases**

Avoided Emissions from Wind Power (1 MWh) Integration

- **Marginal unit of generation from detailed dispatch model**
- **Average unit of generation**
- **Marginal generator emission rates**
- **Modeling construct variance has significant impact**

Sources:
EGRID 2007
Cullen 2010
Novan 2011
Kaffine 2011



	CO_2 tonsCO_2e/MWh	NOx lb/MWh	SO_2 lb/MWh
eGRID Year 2007	0.751	0.8642	3.0015
Cullen 2010	0.79	1.05	3.15
Novan 2011	0.569	0.828	1.545
Kaffine 2011	0.38	0.41	0.88

Methodology Assessment: AQ

Renewable deployment often has pollutant emission co-benefits

- **State-wide , regional reductions in aggregate generation emissions**
- **Deployment can have potential for AQ dis-benefits**
  - localized increases in pollutant emissions
    - Biopower, complementary technologies

- **Importance varies with respect to region**
  - **Existing and expected air quality challenges**
    - SJV , SoCAB
  - **Environmental justice**
  - **Health impacts**
  - **Topographical and meteorological considerations**

- **Robust assessment of regional AQ involves the evaluation of complex spatial and temporal impacts**
  - **Requires the use of sophisticated models**

Methodology Assessment: AQ

Assessment of spatial and temporal air quality impacts

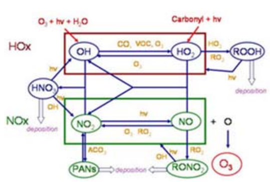
- **Simulation of complex atmospheric chemistry and transport processes to:**
  - Account for physical processes →dilution, transport, mixing
  - Account for chemical processes →formation of secondary pollutants
- **Requires the use of sophisticated models and extensive data inputs**

Input

Meteorology

Emissions

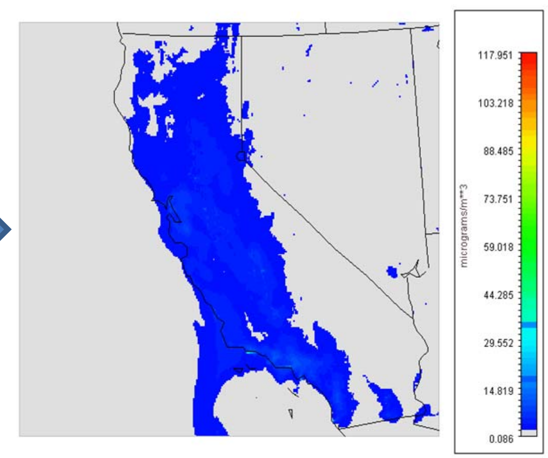
Atmosph. Chemistry



Air Quality Model

- **Dilution, mixing, transport**
- **Photochemical transformation**

Output



P.M.

R & D: AQ

Summary: Comprehensive assessment of AQ impacts

- **Must include all co-deployed technologies**
- **Requires detailed spatial and temporal assessment**
  - NOT just emissions
- **Full understanding and valuation of health benefits from all relevant species**

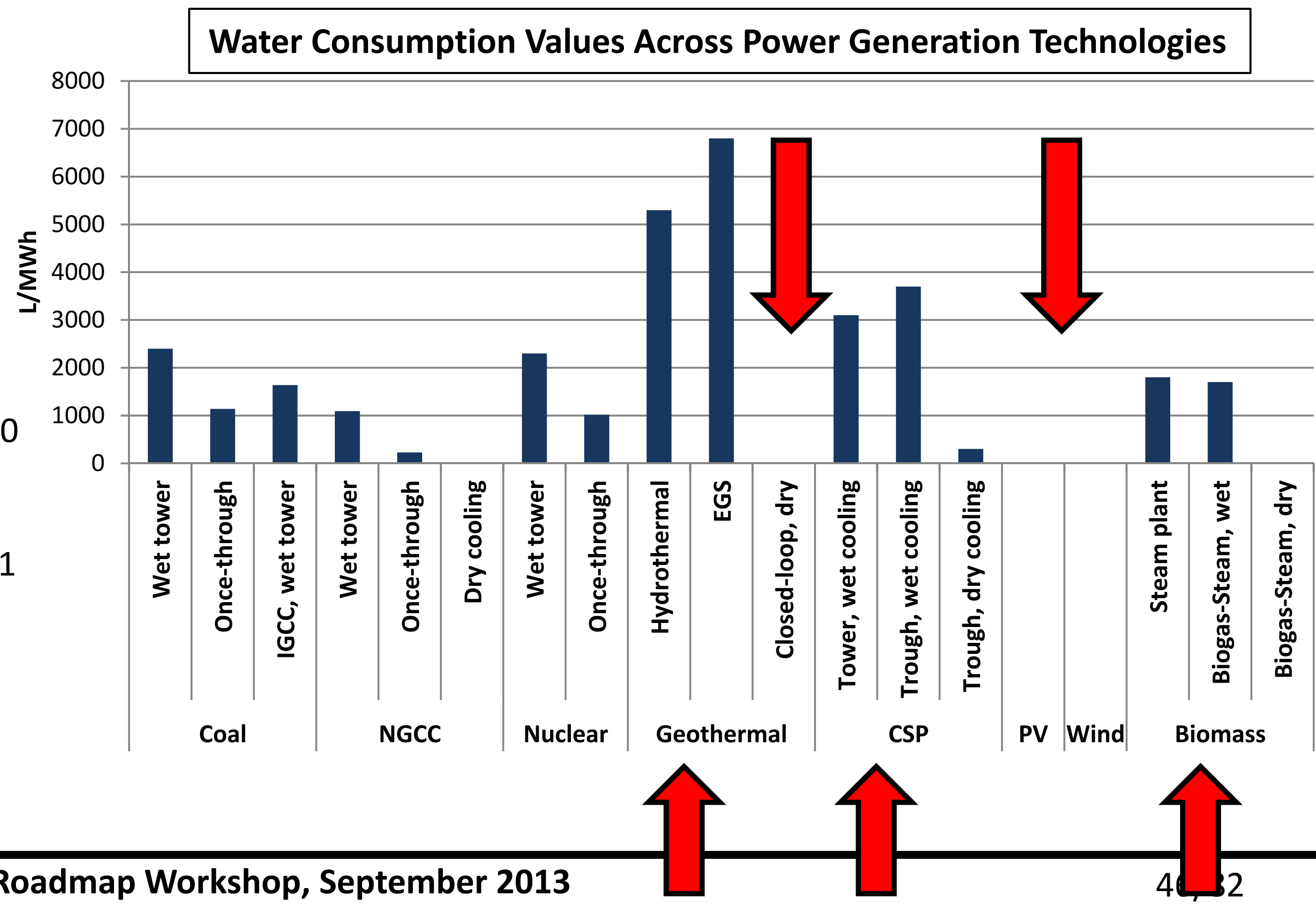
Priority R & D Need	Research Goal			GHG Impacts	AQ Impacts	Water Impacts	Term (S M L)
	1	2	3				
Localized AQ impacts across a broad spectrum of potential future renewable scenarios, e.g., horizons, policies	X				++		S
Impacts of systems-level integration of renewable power e.g., dynamic impacts, low-emission back-up generation	X		X	+++	+++	++	S
Enhanced data availability to support comprehensive, accurate AQ assessment of power plant impacts	X		X		++	++	S
Low-emissions complementary technologies to support grid dynamics with high renewable use		X		++	+++	+	M
Detailed assessment, including economic valuation, of health impacts from reducing pollutant exposure	X		X		++		S-M

Technology Assessment: Water

Renewable technologies can have consumption co- and dis-benefits

- **Dependent on inclusion of thermoelectric cycle**
  - Impacts can be minimized by advanced cooling technologies

Source(s):
Fthenakis 2010
Mielke 2010
Mishra 2011
Macknick 2011



Methodology Assessment: Water

Water resource assessments generally on direct impacts

- **Evaluation of impacts highly site and project specific (CEQA, NEPA)**
  - Plant design → Output, heat rate, operating parameters
  - Plant location → Meteorological conditions (humidity, temperature, wind)
  - Water source → Fresh, saline, degraded/reclaimed

Knowledge Gaps

- **Detailed characterization of water impacts of CA power generation**
  - **Region-, sector- and site-specific water-use inventories**
  - **Water quality impacts**
- **Life-cycle water impacts of various renewable energy technologies**
  - **Increased characterization of upstream and downstream processes**
    - Water quality impacts
- **Systems-level Impacts**
  - **Impacts of grid dynamics on water-use**
    - Spatial and temporal generator dispatch, ramping, start-up effects
  - **Further understanding of water/energy interrelationships**
    - Utilization of energy to transport water for energy generation

R & D: Water

<u>Summary</u>: Improving the state-of-knowledge of power impacts on CA water resources and potential impacts of renewable options

- **Comprehensive understanding of usage, waste streams, and interrelationships at the technology, systems, and regional levels**
- **Detailed LCA for water usage and quality impacts for renewable and gas generation**

Priority R & D Need	Research Goal			GHG Impacts	AQ Impacts	Water Impacts	Term (S M L)
	1	2	3				
Improved understanding and assessment of power generation impacts on California water resources (e.g., inventories, LCA)	X		X			+++	S
Detailed evaluation of CA power plant impacts on water resources, e.g., value of externalities from alternatives	X		X			++	S
LCA water impacts of renewable energy technologies, i.e., increased characterization of up- and downstream processes	X					++	S-M

Technology Assessment: Cooling Impacts

Usage primarily from condensing turbine exhaust steam (cooling)

- **Current methods often comprise wet cooling**
  - Once-through→10-100 times higher withdrawal
  - Recirculating→2 times higher consumption
- **California legislation in place to limit once-through cooling**
  - Requires switch to recirculating or dry cooling

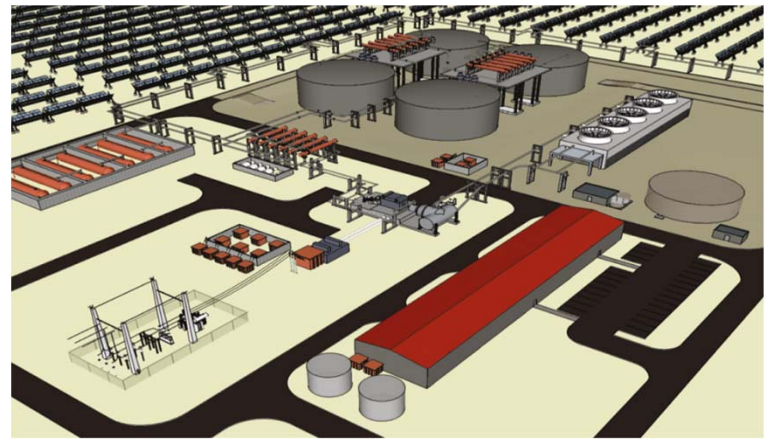
- **Strategies to limit or reduce consumption**
  - **Alternative cooling technologies**
    - Dry (Air) cooling
    - Hybrid cooling

    Require further development to reduce costs and improve performance
  - **Use of alternative water resources when available**
    - Degraded or nonpotable water
      - e.g., contaminated groundwater, irrigation return, industrial wastewater

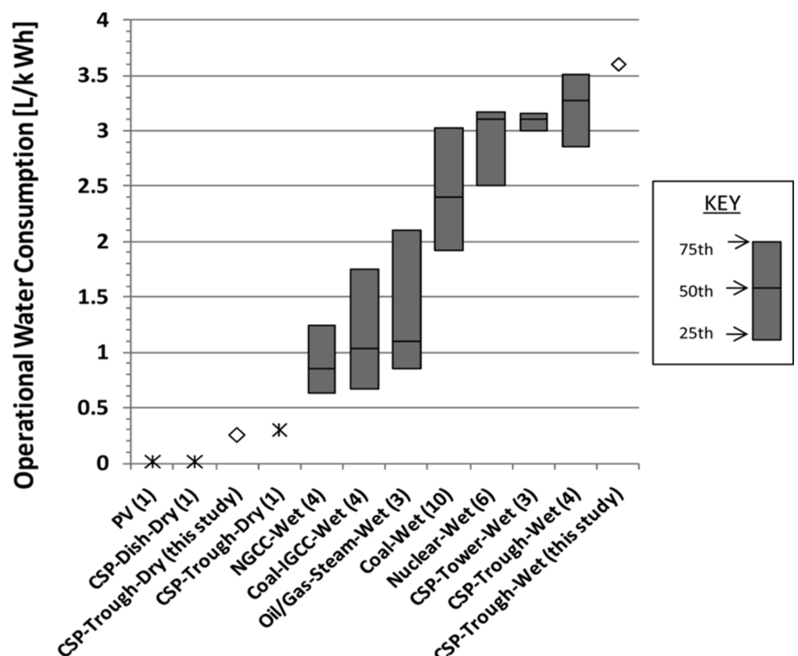
Technology Assessment: Cooling Impacts

Parabolic Trough CST Facility

Capacity: 103 MW
Cooling: Wet
Thermal Energy Storage: Two Tank
TES Medium: Mined Nitrate Salts



Metric	Value	% Change
GHG Emissions (gCO_2eq/kWh)	26	—
Water Consumption (L/kWh)	4.7	—
Energy Demand (MJeq/KWh)	0.40	—
Energy Payback Time (Year)	1	—

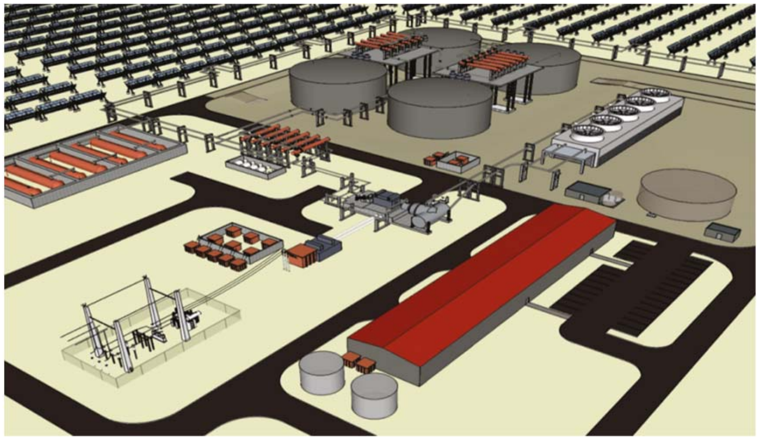


Technology Assessment: Cooling Impacts

<u>Parabolic Trough CST Facility</u>

Capacity: 103 MW
Cooling: Dry
Thermal Energy Storage: Two Tank
TES Medium: Mined Nitrate Salts

Metric	Value	% Change
GHG Emissions (gCO_2eq/kWh)	28	+8%
Water Consumption (L/kWh)	1.1	-77%
Energy Demand (MJeq/KWh)	0.40	+8%
Energy Payback Time (Year)	1.083	+8%



Source: Burkhardt III et al., 2011

R & D: Water

Summary: Support for the progression and demonstration of advanced cooling technologies to minimize withdrawal and consumption

- Improve performance and reduce associated costs
- Further understanding of full range of benefits from dry- and hybrid-cooling systems

Priority R & D Need	Research Goal 1	Research Goal 2	Research Goal 3	GHG Impacts	AQ Impacts	Water Impacts	Term (S M L)
Improved performance of advanced cooling technologies, i.e., dry (air) and hybrid cooling systems • *Cost reduction/efficiency improvements* • *Enhanced performance during non-ideal conditions* • *Deployment/evaluation of CA demonstration projects*		X		+	+	+++	S-M
Improved cost/benefit analyses for advanced cooling accounting for the full range of benefits	X			+	+	+++	S
Characterization and improved understanding of minimization strategies for air emissions from cooling activities	X				+	+	S-M
Evaluation of the use of degraded resources for power generation, e.g., benefits, costs, emissions	X				+	++	S

Outline

- Project Overview
- **Technology and Fuels Identification and Assessment**
  - Technology R&D Needs
  - Impacts (GHG, AQ, Water) R&D Needs
  - **Biopower R&D Needs**
- Co-Benefits Assessment Methodologies
- Discussion

Biopower Assessment

Biopower distinctive amongst renewable energy pathways

- **Includes a highly diverse array of pathways, technologies, resources, products, and end-uses**
  - Potential impacts often complex and sometimes unclear
- **Potential for high co-benefits and significant dis-benefits**
  - Direct air emissions and water consumption from some pathways (dis-benefits)
  - Waste stream pathways can offset air emissions and improve water quality (co-benefits)
  - Additional environmental benefits, e .g., reduced wildfire risk
- **Additional energy benefits**
  - Pathways with dispatchability
  - Economic stimulus, e.g., job creation

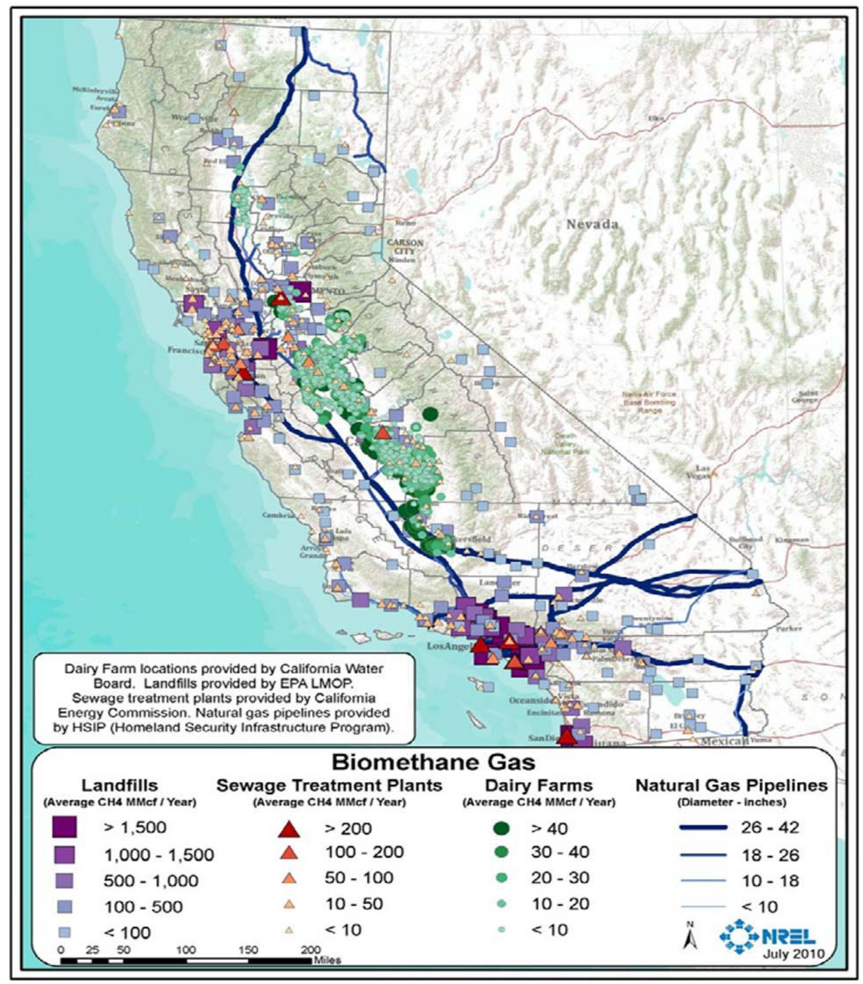
Table 1. Direct Bioenergy Economic Impact Estimates for California (heat energy not included)

Biopower	Feedstock (Million BDT)	Capacity (MW)	Energy (GWh/y)[a]	Direct Jobs[b]	Direct Value (million $)[c]	*Jobs (/Million BDT)*	*Value ($/BDT)*
Current Biopower	9.63	1,000	5,745	5000	$575	519	$60
Projected Additional 50% Biopower	4.82	500	2,873	2500	$287	519	$60
Total Current and Projected	14.45	1,500	8,618	7,500	$862	519	$60

Source: 2012 CA Bioenergy Action Plan

Biopower Assessment

- **Relatively modest contribution to total generation mix to 2020**
  - **2% in 2011**
  - **4% in 2020**
- **In-state resources to support significant capacity additions**
  - **Currently using approx. 15%**
- **Could play important role in future (2050) California grid mix**
  - **Competition with renewable fuel for use in the transportation sector**



Source: Titman et al., 2010

Biopower Assessment

- **Relatively modest contribution to total generation mix to 2020**
  - **2% in 2011**
  - **4% in 2020**
- **In-state resources to support significant capacity additions**
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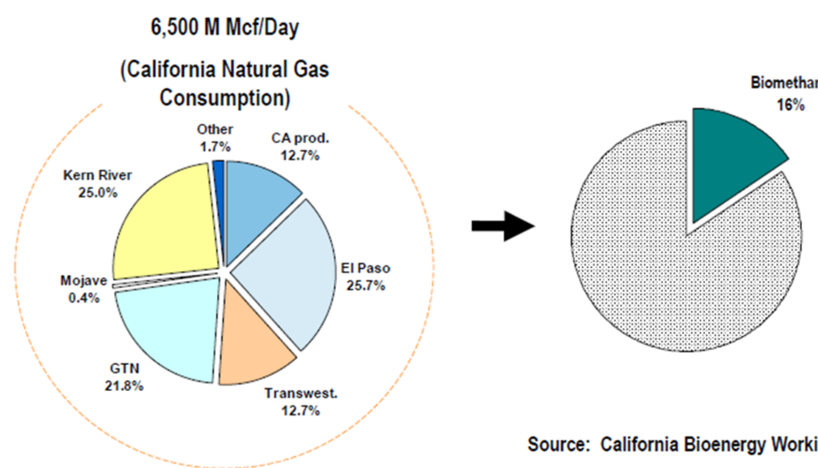
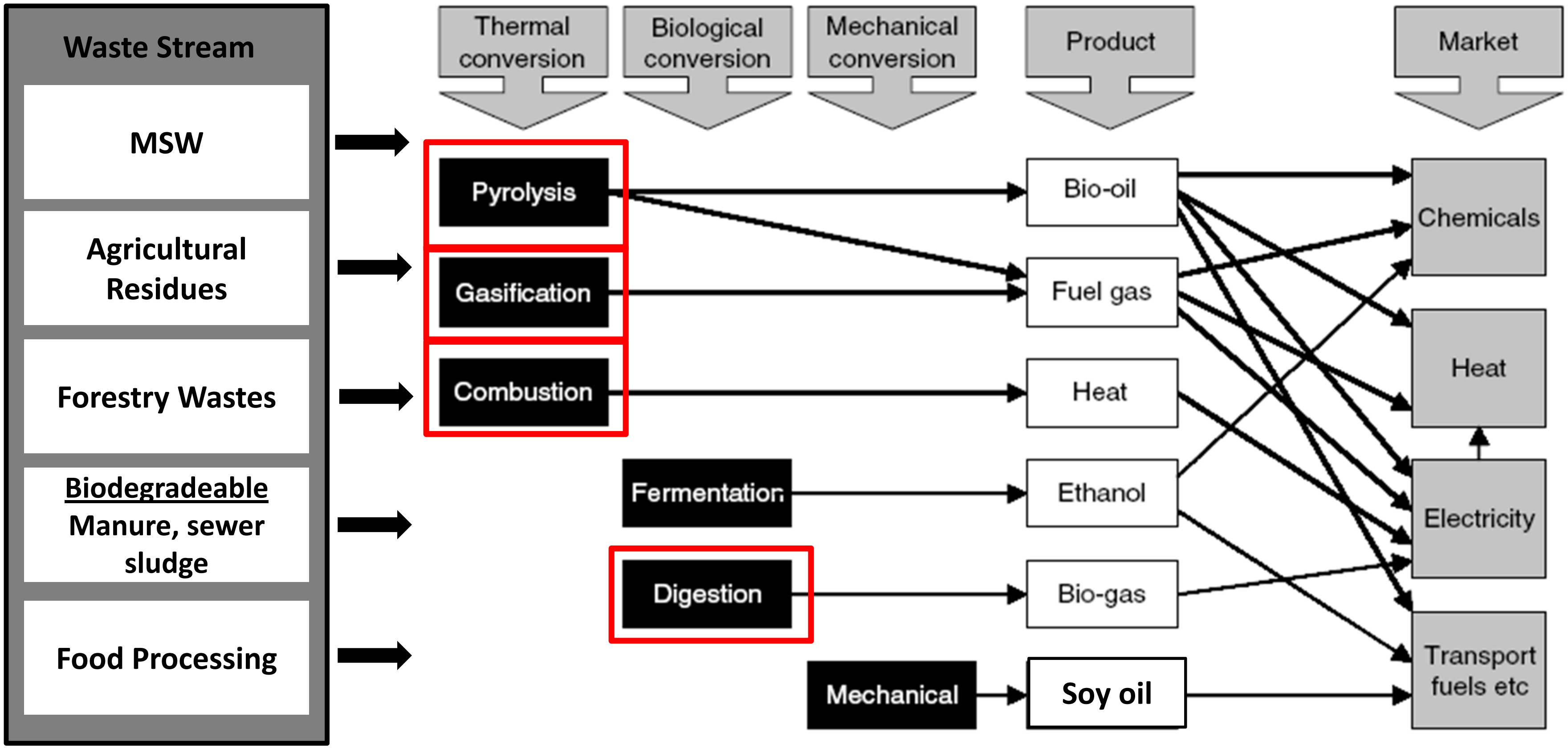


Source: California Bioenergy Working Group

Source: NREL 2010

Biopower Assessment

Diverse range of potential biopower energy pathways



- Various energy conversion technologies have different emissions

Biopower Assessment

Knowledge Gaps

- **Detailed information regarding the availability of suitable waste streams and opportunities for biopower deployment**
- **Preferred uses and strategies for CA biopower resources**
  - **Co-benefits and costs of different pathways**
    - Vehicle fuel, pipeline injection, stationary power production
  - **Sectoral level → Tradeoffs between transportation and power sectors**
  - **Pathways → feedstock, conversion technologies**
- **Available assessment methodologies capable of valuing the broad range of potential co- and dis-benefits from biopower**
  - **Allow for comparison of specific pathways and regions**

Biopower R & D: General

Summary: Complexity and breadth of potential energy procurement strategies from biopower necessitates detailed assessments

- Diverse range of potential co- and dis-benefits
- Important to characterize and consider specific pathways

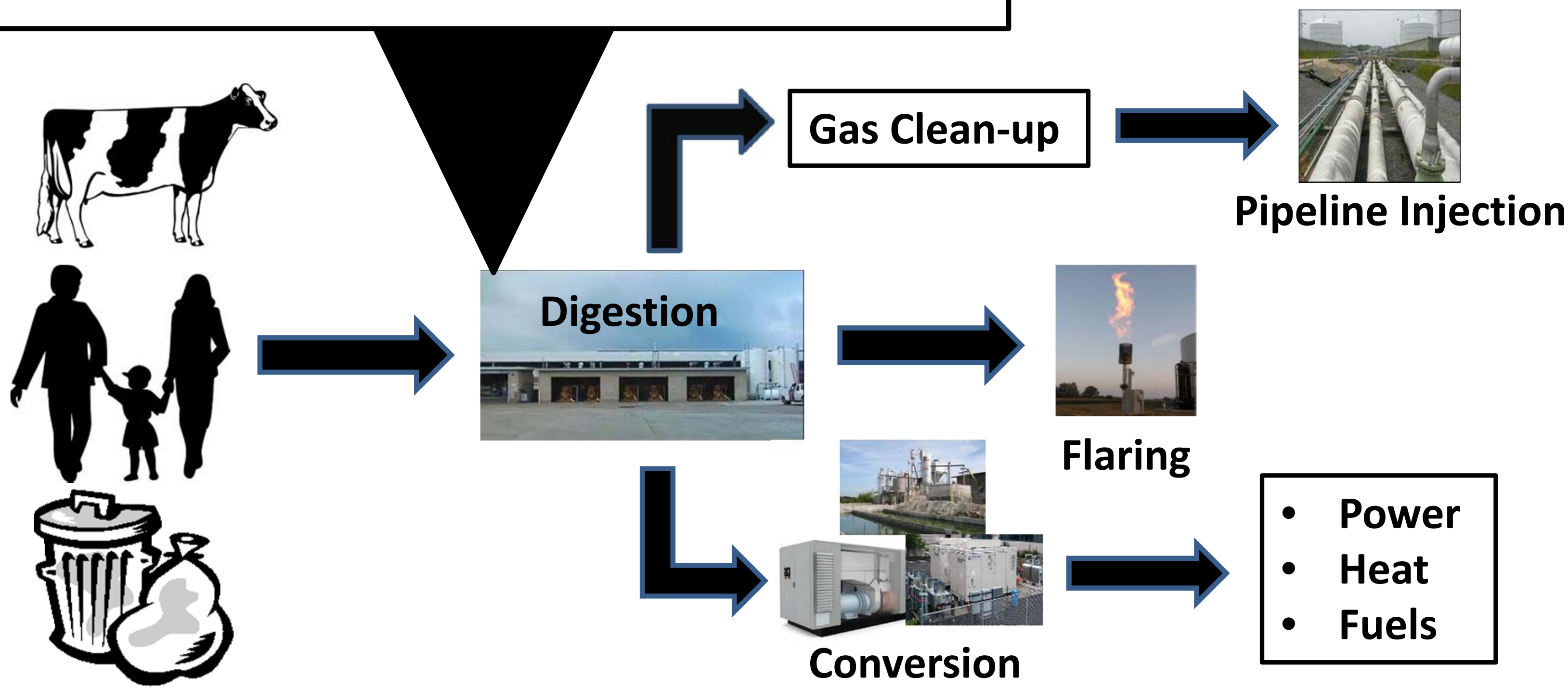
Priority Biopower R & D Need	Research Goal			GHG Impacts	AQ Impacts	Water Impacts	Term (S M L)
	1	2	3				
Detailed assessment of CA biopower resources, e.g., suitable waste streams, energy crops, other bio-resource opportunities, properties, spatial distribution, availability, amount, …	X			+	+	+	S
Comprehensive evaluation to identify preferred uses and strategies for maximum co-benefits of CA resources, e.g., costs/benefits between pathways, sectors, technologies	X		X	+++	+++	+++	S-M
Identify and address regulatory, statutory, and utility interconnection impediments to deployment of biopower	X			+	+	+	S
Develop assessment methodologies to value the broad range of potential Biopower benefits and dis-benefits	X		X	++	++	++	S

Biopower Assessment: Biogas

Biogas pathways offer significant potential for co-benefits

Controlled digestion and flaring

- Significant GHG benefits via avoided CH_4
  - GHG emissions of CO_2
- AQ dis-benefits from criteria pollutant emissions
  - Some AQ benefits (e.g., avoided VOCs)



Biopower Assessment: Biogas

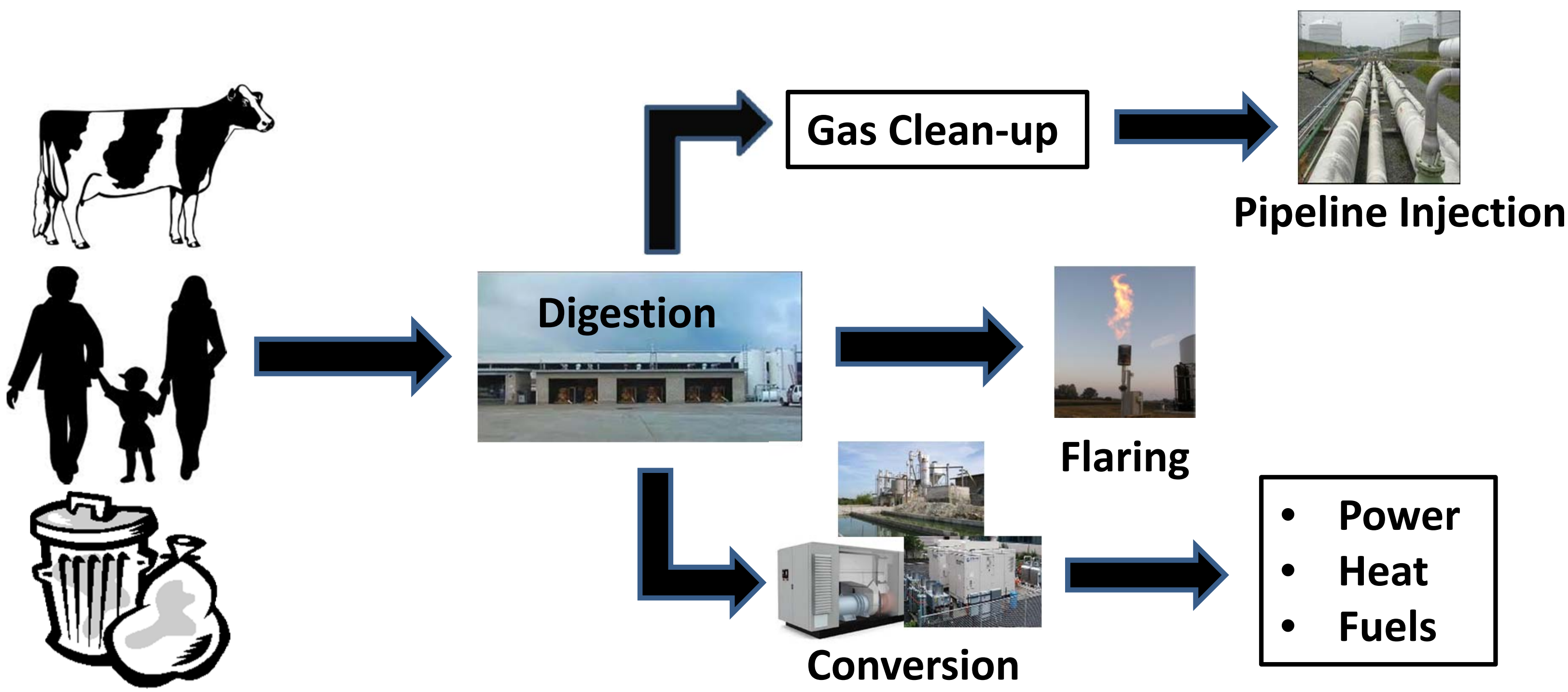
Biogas pathways offer significant potential for co-benefits

GHGs

- Prevention of N_2O emissions
- Capture of methane - 1 MMT CO_2e-AB 32
- Off-set GHG emissions of grid-electricity

Air Quality

- Destruction of VOCs, NH_3, H_2S
- Prevention of flaring emissions
- Off-set pollutant emissions of grid-electricity



Biopower Assessment: Advanced Conversion

Advanced systems can improve:

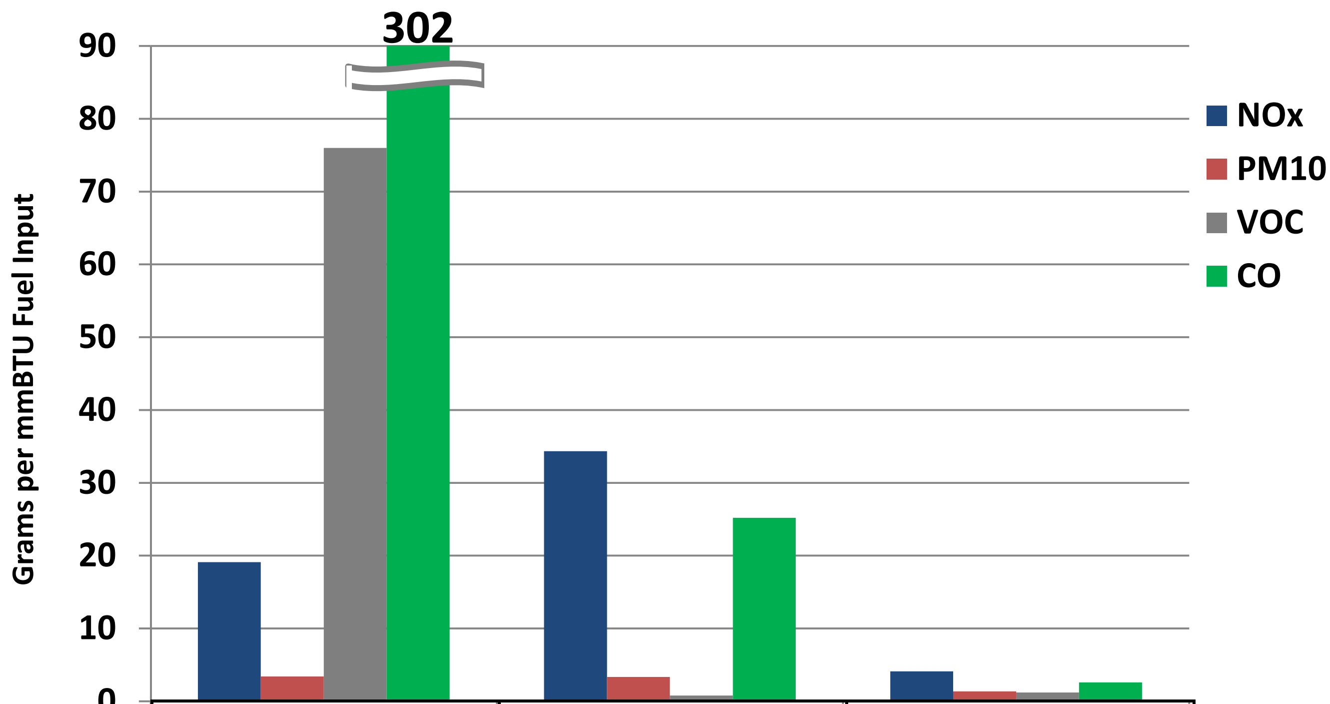
- **Cost**
- **Conversion efficiency**
- **Installed capacity**
- **Environmental performance**
- **Public acceptance**
- **Increased range of feedstock utilization**

System	Benefits	Challenges
Gasification	• Increase range of feedstocks/conversion devices • Allow utilization of existing plants • Potential for reduced air emissions	• System cost and reliability • Generation of pollutants – Tars, SO_2, Particulates
Micro-turbine	• Eliminate water consumption/wastewater streams • Improved emissions performance • Scalable	• System cost and reliability • Reduced efficiencies
Fuel Cell	• Very low emissions • Water neutral • Generation of waste heat, chemical fuels • Scalable	• System cost and reliability

Biopower Assessment: Advanced Conversion

Advanced systems can reduce emissions and improve performance

- Particularly attractive in CHP applications
- Fuel cell pathways include the potential for chemical fuels



Adapted from:
Wang et al., 2010

	Gas - ICE with control	Gas - Microturbine	Fuel Cell (MCFC)
Electrical Efficiency	36%	28%	46%

Biopower R & D: Advanced Conversion

Summary: Assessment and development to support the deployment of advanced biopower technologies and pathways

- Characterization/valuation of benefits to accurately represent costs
- CA deployment and demonstration projects at-scale
- Elucidation of potential unforeseen impacts e.g., liquid discharge from gasification systems

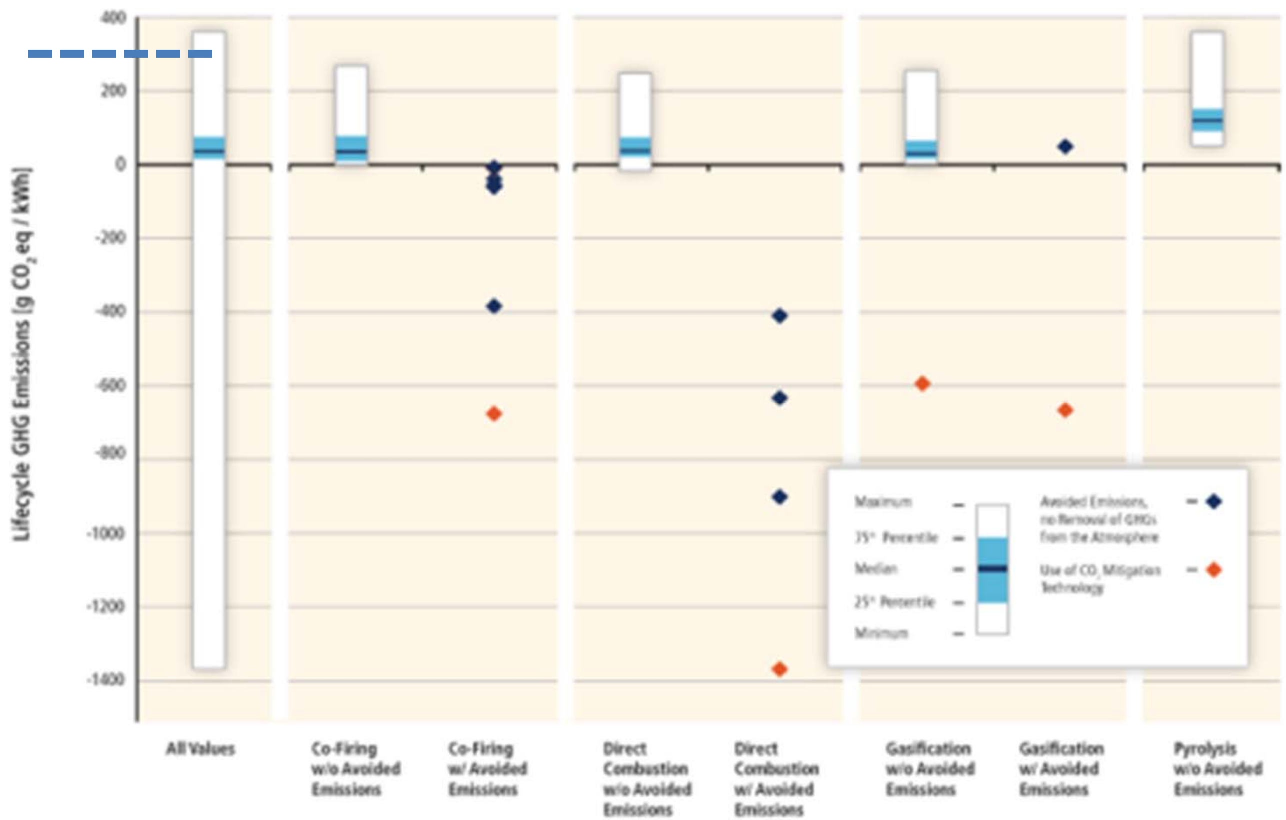
Priority Biopower R & D Need	Research Goal 1	Research Goal 2	Research Goal 3	GHG Impacts	AQ Impacts	Water Impacts	Term (S M L)
More thorough characterization of the potential co-benefits and dis-benefits of emerging advanced conversion devices (e.g., FC, micro-turbine, gasification)	X			+	+	++	S-L
Deployment of commercial scale biomass gasification with CHP demonstration projects		X		++	++	++	M-L
Improved efficiencies and reduced costs for low-emissions conversion equipment (e.g., fuel cells, turbines) operating on renewable fuels		X		+	++	+	S-M

Biopower Assessment: GHG

Biopower LCA GHG impacts range dramatically by pathway

- **Dedicated crops can exceed low end estimates for natural gas**
- **Waste streams offer the potential for sequestration**

Natural Gas 306 g/kWh (Low-end)



Source: NREL 2010

Biopower R & D: GHG

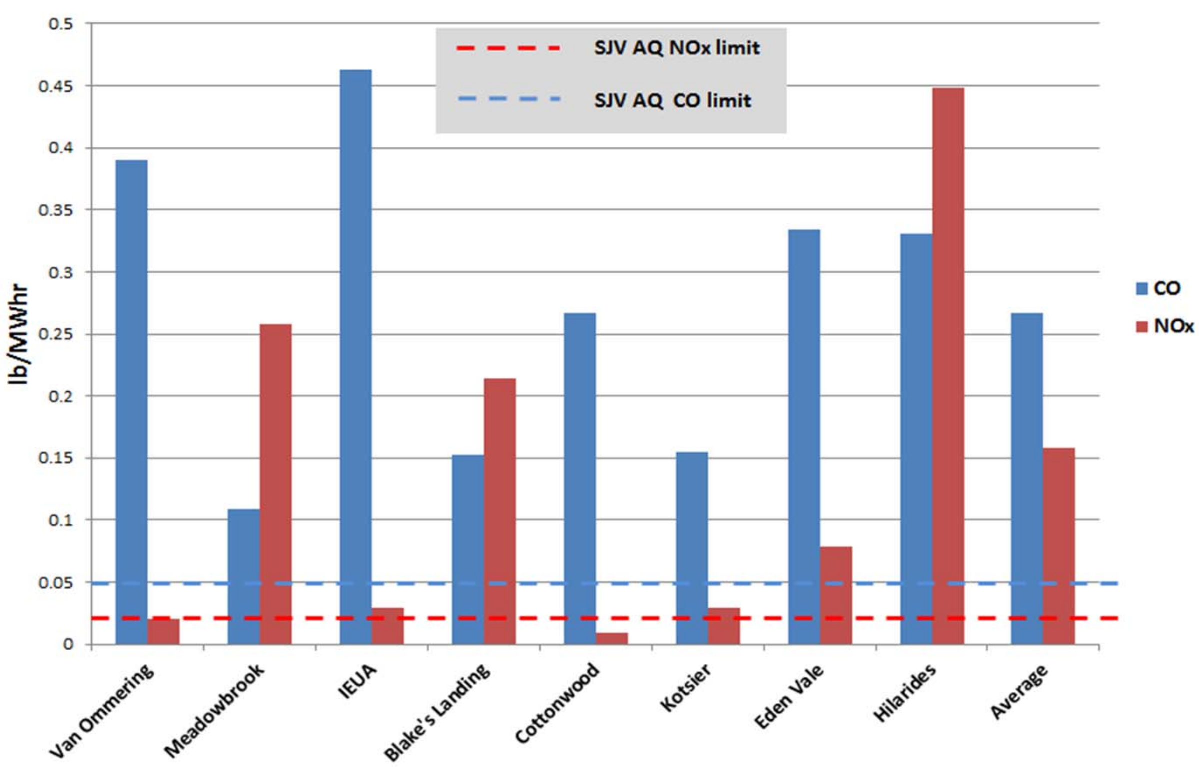
Summary: Biopower pathways have the potential for both the highest GHG co- and dis-benefits

- Emphasizes the importance of considering specific situations
- Prioritize the use of waste-streams over energy crops

Priority Biopower R & D Need	Research Goal			GHG Impacts	AQ Impacts	Water Impacts	Term (S M L)
	1	2	3				
Thorough, detailed LCA for biopower strategies specific to CA, including various pathways, technologies, etc.	X			+++	+	+	S-M
Assessment and inclusion of off-set GHG emissions in estimates for CA policy impacts, e.g., flaring, controlled burning	X			++	+	+	S
Analysis of current and emerging bio-resource (e.g., waste water treatment, landfill, agriculture & forest waste) & subsequent biopower emissions	X			++	+	+	S

Biopower Assessment: AQ

Air emissions from current generation technologies major hurdle for deployment of biopower systems in some CA regions



Source:
CEC-500-2009-009

Biopower Assessment: AQ

Air emissions from current generation technologies major hurdle for deployment of biopower systems in some CA regions

- **Direct**
  - Primarily reciprocating engines, boiler combustion (high emissions)
- **Indirect**
  - Feedstock related processes →Gathering, transport, storage

- **Distribution of resources concentrated in areas with poor AQ**
    - E.g., agricultural residue, dairy wastes in the SJV
  - **Costly pollutant control strategies→ Project cancellation/suspension**

- **Important to consider life cycle emissions impacts**
  - **Off-set of waste stream related emissions**
    - E.g., controlled burning of biomass, flaring emissions of biogas

Biopower R & D: AQ

Summary: Strategies to reduce emissions of biopower systems

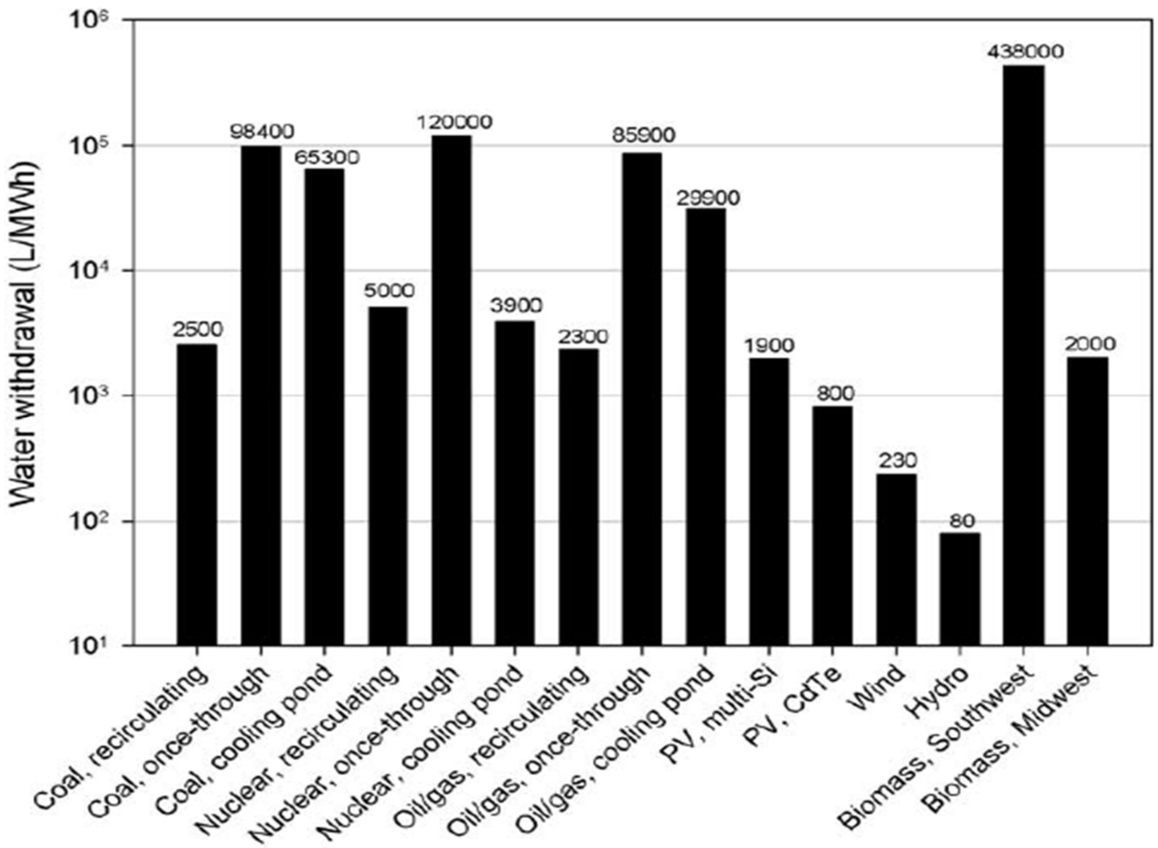
- **Barriers to deployment of no- and low-NOx systems → FCs, pipeline inj.**
- **Advanced pollutant control technologies (e.g., engine controls)**
- **Generation of HAPs via Biogas, Biomass, MSW and other pathways**

Priority Biopower R & D Need	Research Goal			GHG Impacts	AQ Impacts	Water Impacts	Term (S M L)
	1	2	3				
Development/commercial demonstrations of no- and low-NOx biopower systems, e.g., FC, pipeline injection, microturbine		X		++	+++	++	S-M
Detailed regional/local assessment of impacts with spatial resolution across range of future year scenarios, pathways, source locations, magnitudes	X			+	+++	+	S
Hydrogen enriched fuel gas for lean burn engine application		X		+	++	+	S
Development of advanced pollutant control technologies for traditional conversion devices, e.g., reciprocating engines		X		+	++	+	S
Investigation of hazardous air pollutant emissions and strategies to mitigate impacts	X	X			+		S
Novel permitting procedures to support deployment in regions with poor AQ. Should incorporate offset emissions, e.g., flaring	X		X	++	+++	++	S-M

Biopower Assessment: Water

Biopower can have pathway-specific water co- and dis-benefits

- **Waste streams with advanced conversion devices beneficial**
- **Dedicated energy crops in the Southwest increase usage**



Source: Fthenakis & Kim 2010

Biopower R & D: Water

Summary: Need for enhanced assessment of biopower water impacts and development of strategies for minimizing impacts

- **Withdrawal and consumption requirements for various pathways**
- **Strategies to reduce usage e.g., co-deployment of advanced cooling**
- **Elucidation of quality concerns e.g., liquid discharge from gasification**

Priority Biopower R & D Need	Research Goal			GHG Impacts	AQ Impacts	Water Impacts	Term (S M L)
	1	2	3				
Detailed assessment of water usage, i.e., withdrawal and consumption, from various biopower pathways	X		X			++	S
Assessment and development of strategies to minimize water usage, e.g., advanced conversion devices and cooling technology	X	X				++	S-M
Elucidation of potential water quality impacts, e.g., liquid discharge from gasification pathways, contamination, leachate	X					++	S-M

Outline

- Project Overview
- Technology and Fuels Identification and Assessment
  - Technology R&D Needs
  - Impacts (GHG, AQ, Water) R&D Needs
  - Biopower R&D Needs
- **Co-Benefits Assessment Methodologies**
- Discussion

Introduction

Co-benefit Assessment Methodologies

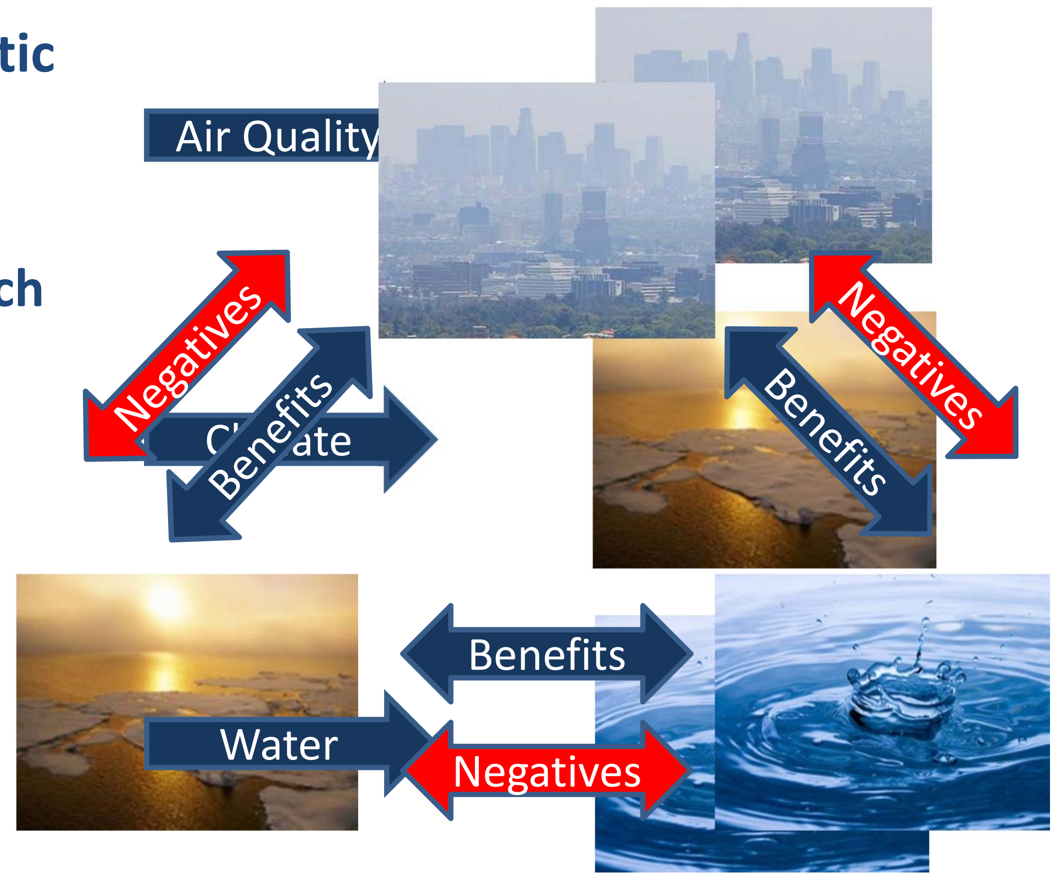
- **Focus on environmental co-benefits associated with renewable power generation**
  - **AQ, GHG, and water resource impacts**
  - **Identify and/or discuss other relevant environmental endpoints**

- **Evaluate current methods used to determine and assess co- and dis-benefits from renewable power impacts**
  - **Identify knowledge gaps and suggest research needs to improve current methods and develop new assessment methodologies**

Co-benefits Assessment Methodologies

- **Historical approach individualistic**
  - Analyses of singular endpoint
  - Lacking comprehensive structure

- **Importance of co-benefit approach**
  - Optimize design & deployment of California policies and programs
  - More fully represent the cost and benefits of renewable power
  - Impact stakeholder positions & garner support for policy



Methodologies that can analyze and identify opportunities to maximize benefits and minimize costs across multiple endpoints

Co-benefits Assessment Methodologies

Comprehensive analyses require weighting of impacts

- **Facilitate comparison among deployment strategies**
- **Accurate assessment of true "value" of technologies and pathways**
  - E.g., Avoided waste stream monitoring from dry cooling

- **Accurate quantification of endpoints are challenging**
  - **Lack of standardized metric**
  - **Valuation of impacts can vary between entities/individuals**

Benefit	Value	Value	Cost
Human health impacts	?	?	Increased water consumption
Energy Security	??	??	Aesthetics
Land-use	???	???	Flora and Fauna

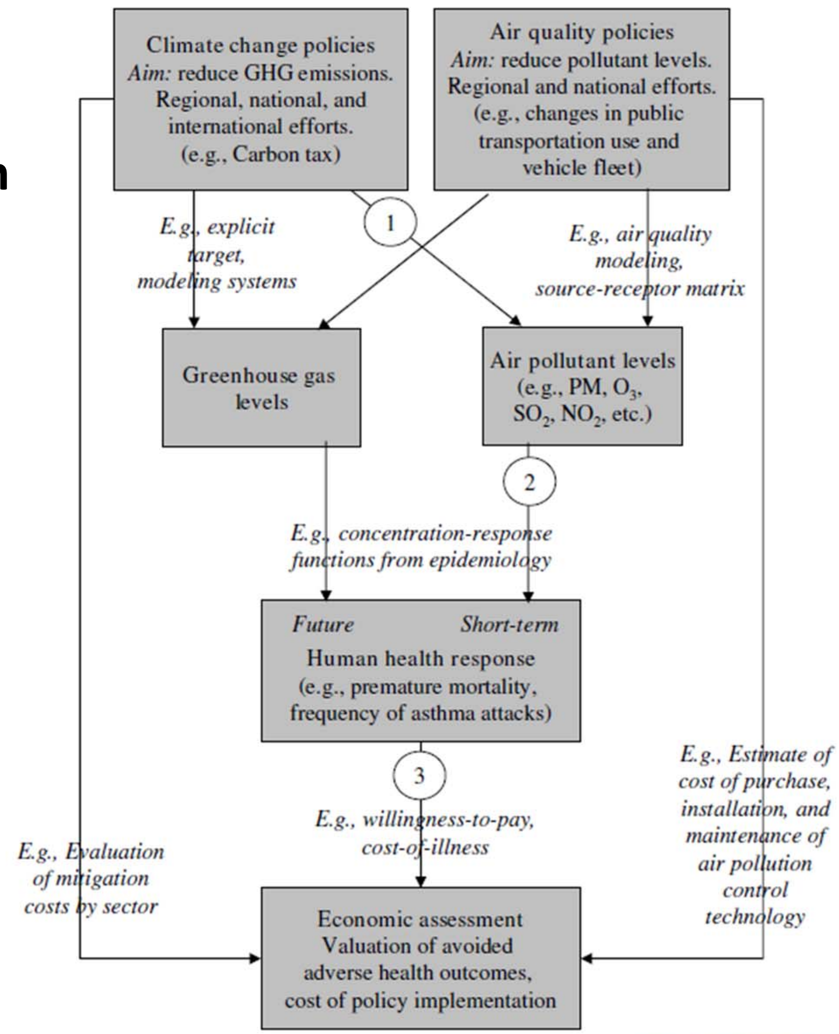
Co-benefits Assessment Methodologies

Relationship between AQ and climate change policies requires estimation of:

1. **Air pollutant concentration perturbation**
2. **GHG emissions perturbation**
3. **Avoided adverse health endpoints**
4. **Economic valuation of health consequences**

- **Most assessments concentrate on one framework aspect**
- **Underestimated estimates due to important non-valued benefits**

- **No inclusion of additional endpoints**
  - **E.g., water considerations**



Source: Bell et al., 2008

Co-benefits Assessment Methodologies

Renewables can have costs and benefits across a wide range of environmental impact categories other than AQ, GHG, and water

- Aesthetics
- Agricultural Resources
- Biological Resources
- Cultural Resources
- Geology/Soils
- Acidification
- Hazardous Materials/Waste
- Land Use
- Recreation
- Transportation/Traffic
- Population/housing
- Eutrophication

- **Often challenging to quantify impacts in terms of weighting endpoints for decision making**
  - Valuation varies across entities
  - Lack of consistent data
- **California decision makers need system for evaluating and ranking such impacts in the absence of comparable standards**

Co-benefits Assessment Methodologies

<u>Knowledge Gaps</u>

- **Comprehensive framework for evaluating multiple endpoints**
  - **Optimize deployment of renewable resources across various co- and dis-benefit categories**
  - **Valuation of full range of costs an benefits of technologies and pathways**
  - **New methods for assessing un-quantified and non-valued benefits**

- **Increased data availability and reliability for various assessments**
  - **Assessment methodologies require large amounts of specialized data**
    - AQ Modeling → Emissions Inventories, meteorological fields,
    - Grid modeling → Generator location, operation, emissions
    - GHG LCA → Various diverse data inputs
  - **Need for enhanced data collection, verification and accessibility**

Co-benefits Assessment Methodologies

Initial Workshop Feedback

- **Significant need for new/improved methodologies for analyzing co-benefits**
  - **Established, accepted, transparent, universal**
    - Valuation of co-benefits not universally accepted
  - **Defined scope and baseline for comparison**
    - Displaced new capacity vs. replacing existing

- **Current cost/benefit analyses of renewable power lacking inclusion of co-benefit impacts**
  - **Lack of appropriate, standardized methodology**
  - **Challenges identifying/quantifying impacts**
    - Complex relationships → e.g., ozone and climate change
    - Indirect impacts →e.g., wind kinetic effects
    - Individualistic valuations

Co-benefits Assessment Methodologies

Potential metrics to assist methodology development

- **Disability-Adjusted Life Year (DALY) used by Institute for Health Metrics and Evaluation and WHO**
  - Quantification of the burden of disease from mortality and morbidity
    - One lost year of "healthy" life
  - Measure gap between current and ideal health situation

Suggested key principles and assumptions[1-2]

- **Data attainment and analysis**
  - Multiple types of evidence supporting observations
- **Address uncertainty –** important to convey strength of evidence
  - Uncertain estimate for sparse data better than no estimate
- **Consistency –** important for justification and accurate comparison
  - Observed effect in multiple independent studies
- **Iterative approach to estimation –** new data and methodological innovation will require revision of estimates over time
- **Comprehensive comparisons**
  - Results may better facilitate comparison rather than prediction

Source(s): [1] IHME Protocol 2013, **[2]** U.S. EPA Integrated Science Assessment 2009

R & D: Co-benefits Assessment Methodologies

Summary: Development of a comprehensive framework for evaluating co- and dis-benefits of various pathways

- **Evaluation of optimized renewable pathways across multiple co- and dis-benefit impact categories**
- **Adaptable to respond to future changes**

Priority R & D Need	Research Goal			GHG Impacts	AQ Impacts	Water Impacts	Term (S M L)
	1	2	3				
Novel, enhanced methodologies for identifying and valuing the full range of co-benefits from renewables • *Proper methodologies for individual assessment areas* • *Standardized weighting methodologies for impacts* • *Valuation of full range of costs and benefits of technologies and pathways*	X		X	++	++	++	S-L
Assessment of additional environmental and energy impacts (e.g., land-use, ecological) for co-benefits	X		X				S-M
Enhanced data availability and reliability to support comprehensive methodology development	X		X				S

Assessment Methodologies: AB 32

- **Analysis of co- and dis-benefits required under AB 32**
  - **38501.h - "maximize additional environmental and economic co-benefits"**
  - **38562.b.6 – Overall societal benefits considered for measure adoption**

- **Co-benefits analysis focused on AQ impacts**
  - **Quantification of additional pollutant emissions reductions**
  - **Quantification of resulting public health benefits**

- **Based on direct emissions perturbations**
  - **Focused on $PM_{2.5}$ impacts only**
  - **Additional benefits from ozone reduction**

- **Other health benefits of measures**
  - **Regional transportation measures encouraging walking and biking**
  - **Potential mitigation of climate change public health impacts**

Assessment Methodologies: AB 32

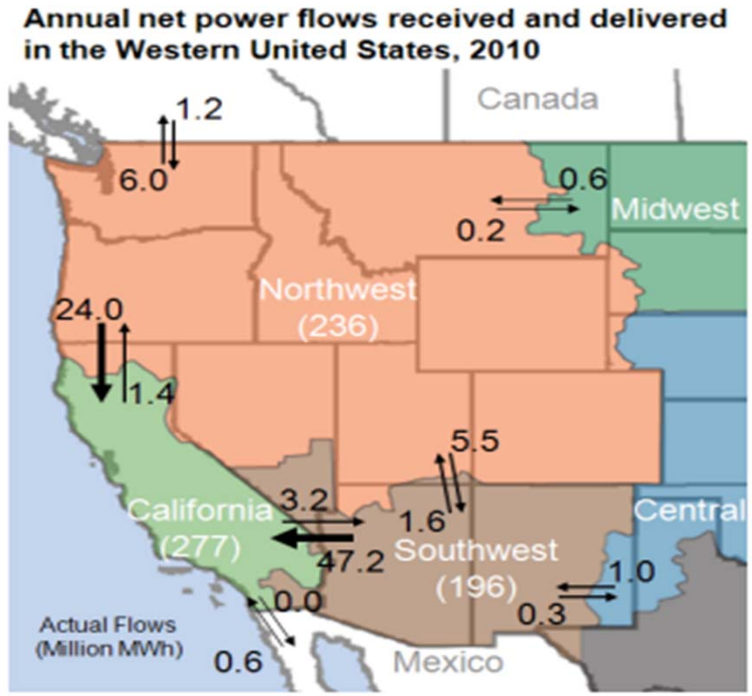
Health Endpoint	Health Benefits of Existing Measures and 2007 SIP *mean*	Health Benefits of Recommendations in the Proposed Scoping Plan *mean*
Avoided Premature Death	12,000	780
Avoided Hospital Admissions for Respiratory Causes	1,300	87
Avoided Hospital Admissions for Cardiovascular Causes	2,600	170
Avoided Asthma and Lower Respiratory Symptoms	190,000	12,000
Avoided Acute Bronchitis	15,000	980
Avoided Work Loss Days	1,200,000	77,000
Avoided Minor Restricted Activity Days	7,000,000	450,000

Measure	NOx	PM2.5
Light-Duty Vehicle • Pavley I and Pavley II GHG Standards • Vehicle Efficiency Measures	1.6	1.4
Goods Movement Efficiency Measures	16.9	0.6
Medium and Heavy-Duty Vehicle GHG Emission Reduction • Aerodynamic Efficiency • Hybridization • Engine Efficiency	5.6	0.2
Local Government Actions and Regional Targets	8.7	1.4
Energy Efficiency and Conservation (Electricity)	7.0	4.0
Energy Efficiency and Conservation (Natural Gas)	10.4	0.8
Solar Water Heating	0.3	0.03
Million Solar Roofs	1.0	0.6
Renewables Portfolio Standard	9.8	5.6
Total	**61**	**15**

Source: CARB 2009 Climate Change Scoping Plan

Assessment Methodologies: CA

- **California imports significant amounts of energy resources**
  - **Power- 2011 30%**
  - **Natural Gas-2010 88%**
- **Spatial profile of consequences**
  - **GHG → Global, no boundary**
  - **AQ → Regional/local effects**
  - **Water → Regional/local effects**
  - **Other → Regional/local effects**
- **Out-of-state impacts**
  - **Could be larger than in-state**
    - GHG →0.6 tons vs. 0.4 tons CO_2/MWh
  - **Potential for out-of-state benefits at the expense of California dis-benefits**



Source: U.S. EIA 2011

Assessment Methodologies: CA

Knowledge Gaps

- **Evaluation of potential future policies & programs and how current CA policies are implemented using methodologies**
  - **Initial assessments complete but require further elucidation with more in-depth methodologies**
    - Power systems modeling → Emissions and water impacts
    - Air quality modeling → Simulations of atmospheric processes
    - Health impacts → Receptor-based modeling of ozone to determine population exposure and potential health impacts

Initial Workshop Feedback

- **CA policy should be guided/developed to incentivize RER pathways with high co-benefits**
  - **Requires new/improved methodologies for analyzing co-benefits**
  - **Need for integrated energy policy studies in CA**
    - Account for various differences in institutional control in 2050, etc.

Assessment Methodologies

<u>Knowledge Gaps</u>

- **Potential availability and reliability of data**
  - **Assessment methodologies require large amounts of specialized data**
    - AQ Modeling → Emissions Inventories, meteorological fields,
    - Grid modeling → Generator location, operation, emissions
    - LCA → Various diverse data inputs

- **Need for enhanced data collection and accessibility**
  - **Federal, State, regional databases**
  - **Co-operation between entities**
  - **Other**

- **Verification of collected data and inventories**
  - **Transparent methodologies**
  - **Independent analyses**

Assessment Methodologies: Permitting

<u>Knowledge Gaps</u>

- **Permitting process considerable hindrance to deployment of renewable and transmission projects**
  - **California Environmental Quality Act (CEQA) requirements**
  - **Federal- National Environmental Policy Act (NEPA)**

- **AQ regulation heavily impacts biopower deployment**
  - **New/existing generation facilities**
    - Local air district permitting →Regional restrictions (e.g., SJV, SoCAB)

- **Example: Tehachapi Renewable Transmission Project**
  - **SCE filed application in June 2007**
  - **Construction began in April 2010 → Roughly 50% complete**
  - **Estimated completion is Summer 2015 (originally 2013), could be longer**

R & D: CA Assessment Methodologies

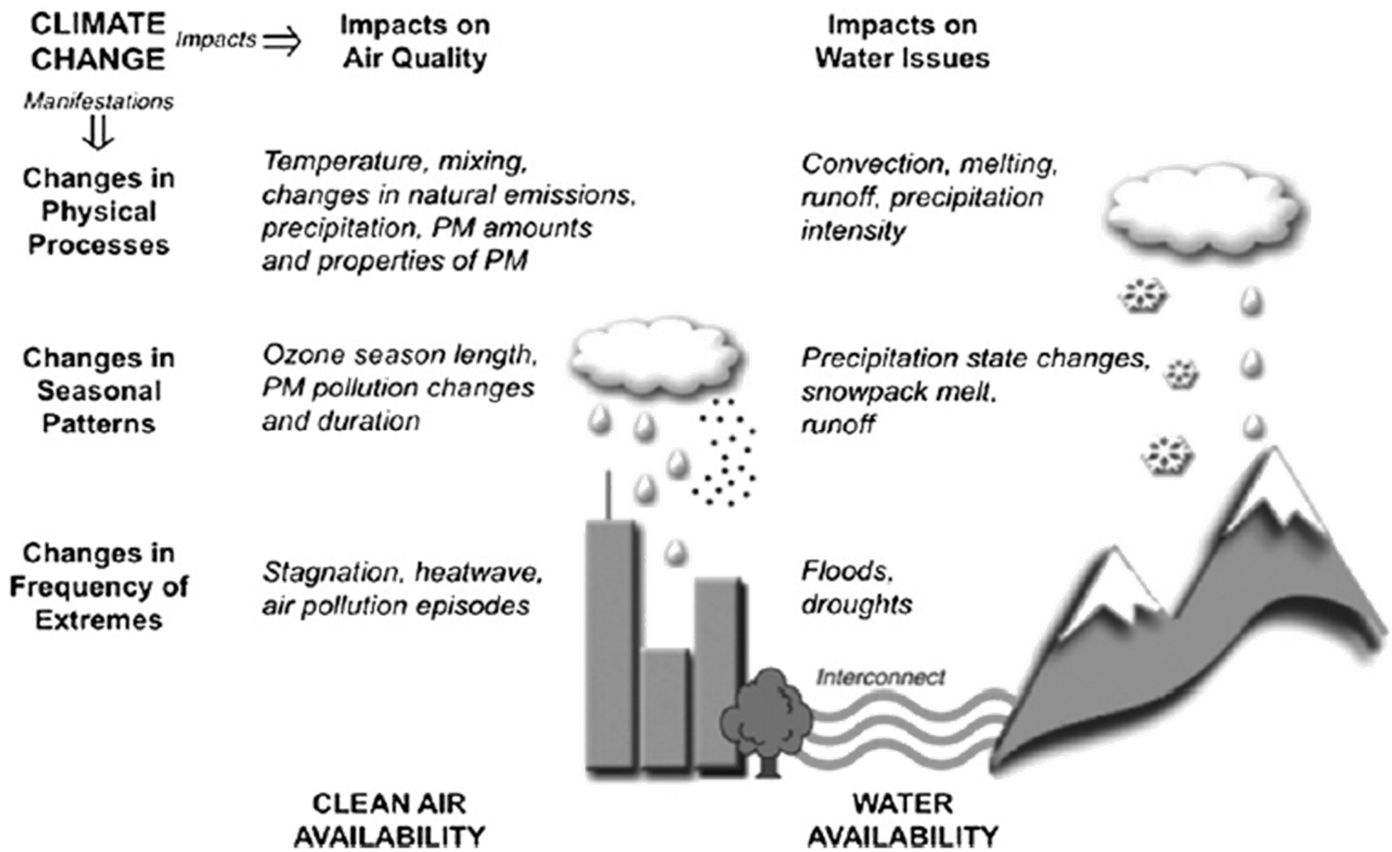
Summary: Need for enhanced co-benefit assessment of current and future CA policies, programs, and potential opportunities

- **More thorough evaluations, e.g., secondary pollutant formation for AQ**
- **Identification and pursuance of high co-benefit opportunities, e.g., specific sectors, locations, situations**

Priority R & D Need	Research Goal			GHG Impacts	AQ Impacts	Water Impacts	Term (S M L)
	1	2	3				
Detailed evaluation of future California policies and programs & implementation of current policies from a co- and dis-benefits perspective	X			++	++	++	S
Identification and assessment of sectors and opportunities in California for high co-benefits, e.g. ports, SJV	X			++	++	++	S
Acquisition, verification & access to specialized data (e.g., emissions Inventories, meteorological fields, grid features)							
Consideration of regional level interactions and impacts (e.g., out-of-state vs. in-state impacts)	X		X	+	+	+	S
Improve permitting procedures for renewable projects that have the potential for high co-benefits	X			++	++	++	S-M
Assessment of future siting methods to locate various renewable projects with maximization of co-benefits	X			+	++	++	S-M

Assessment Methodologies: Climate Change

Climate change projected to have major impacts in CA



Assessment Methodologies: Climate Change

Climate change projected to have major impacts in CA

- **Temperature**
  - Mean summer temperature increase [1]
    - 2035 → .6-2.1 °C
    - 2070 → 1.7-3.4 °C
  - Increase 4-8 times of heat wave events[2]
- **Water Resources**
  - Increased drought conditions [3]
  - Reduction in snow pack 30-70%[2]
- **Air Quality**
  - Regional ozone increases of 3-10%[4]

[1] Cayan et al., 2005
[2] Hayhoe et al., 2004
[3] Seager et al., 2007
[4] Steiner et al., 2005

Assessment Methodologies: Climate Change

Regional climate perturbations can have major CA grid impacts

- **Demand**
  - Increased (1-10%) electricity consumption due to cooling need [1][2]
  - Climate-induced load growth for 2005-2034 of 1-5% peak demand[2]
- **Supply**
  - Reduced operating efficiencies from thermal power plants
    - Lack of available water for wet cooling
  - Reduced renewable generation → Hydropower
  - Altered renewable generation → Solar, wind (positive and/or negative)
- **Transmission**
  - Reduced capacity from thermal line expansion
  - Increased transmissions constraints during high load conditions
  - Increased risk of wildfire threat to transmission lines

[1] Sailor 2001 **[2]** Franco & Sanstad 2006

Assessment Methodologies: Climate Change

Knowledge Gaps

- **In-depth understanding of interdependence and potential impacts of climate change on CA resources and energy sectors**
  - **Interactions between climate, regional AQ, water, and other impacts**
  - **Impacts of climate on power demand and grid operation**
  - **Interdependence of sustainable development and mitigation and adaption measures**

- **Methodologies to conduct detailed evaluations of links between climate change and California resources and energy sectors**
  - **Account for complex interrelationships and incorporate co- and dis-benefits of such interactions**
  - **Identification of potential developmental paths California can pursue to successfully address multiple concerns**

R & D: Climate Change Assessment Methodologies

Summary: Need for development of novel methodologies that can:

- Account for interrelationships between physical impacts and variables
- Integrate adaption and mitigation strategies into assessment capabilities
- Account for and assess various climate impacts on CA power generation

Priority R & D Need	Research Goal			GHG Impacts	AQ Impacts	Water Impacts	Term (S M L)
	1	2	3				
Increased understanding of impacts and interrelationships of climate change on co-benefit impact categories. E.g., : • *Temperature impacts on generator efficiencies* • *Temperature impacts on load demands* • *Impacts of climate change on respiratory health*	X		X	++	++	+++	S-L
• Evaluation of health impacts of reducing GHG under AB 32	X		X	++	++	++	S-M
• Identification of effective approaches for the mitigation, avoidance, and adaption to possible impacts	X			++	+++	+++	S-L

Outline

- Project Overview
- Technology and Fuels Identification and Assessment
  - Technology R&D Needs
  - Impacts (GHG, AQ, Water) R&D Needs
  - Biopower R&D Needs
- Co-Benefits Assessment Methodologies
- **Discussion**

Thank You!

Questions and Discussion

- **Critique of proposed RD&D needs**
- **Suggestions for future areas of research**
- **Other …**

Please send any additional written comments to Marla Mueller at marla.mueller@energy.ca.gov before October 3, 2013